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A Methodology for Evaluating Military Systems
in a Counterproliferation Role

THESIS

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ABSTRACT

This thesis develops a methodology to evaluate how dissimilar military systems support the accomplishment of the United States' counterproliferation objectives. The overall scope is to develop a model of the counterproliferation decision process that enables systems to be evaluated against common criteria. By using decision analysis, an influence diagram model is developed which represents military activities in the counterproliferation process. The key questions which must be asked in evaluating counterproliferation systems are highlighted. An analysis of perfect intelligence, perfect defensive and perfect offensive systems revealed that a perfect intelligence system provides the greatest potential to meet the United States' counterproliferation objectives. Sensitivity analysis is conducted to determine which factors in the model are most important.

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A METHODOLOGY FOR EVALUATING MILITARY SYSTEMS IN A COUNTERPROLIFERATION ROLE

I. Introduction

Background

With the dissolution of the Soviet Union, another threat to the United States' national security has become increasingly important. This threat is the proliferation and the potential use of weapons of mass destruction (WMD). Weapons of mass destruction are generally classified as nuclear, chemical, and biological weapons capable of causing large scale destruction of life and infrastructure. In the past, the U.S. used a policy of deterrence to prevent the use of WMD by the Soviet Union. However, it is becoming increasingly apparent, especially in countries such as North Korea and Iraq, that deterrence alone will not prevent WMD proliferation. In order to deal with this problem, the Department of Defense (DOD) has developed a policy to counter the proliferation of weapons of mass destruction.

"To proliferate" is defined by Webster's dictionary as, "to grow by rapid production new parts, cells, buds or offspring." The proliferation of WMD refers to the spread of the technology, hardware, and weaponry associated with nuclear, chemical, and biological weapons and the means used to deliver them, to countries around the world. This spread of weapons and delivery systems could threaten the United States' interests at home and abroad. Without proper safeguards, WMD could end up in the hands of individuals, organizations, or nations who might see fit to use them against the interests of the United States.

The current U. S. policy of nonproliferation was announced by President Clinton in an address to the United Nations on September 27, 1993. He stated,

"One of our most urgent priorities must be attacking the proliferation of weapons of mass destruction--nuclear, chemical, and biological weapons--and the ballistic missiles that can rain them down on populations hundreds of miles away. ... I have made nonproliferation one of our nations highest priorities." (13:2)

With this statement of policy, the President made it clear that proliferation of WMD by other countries would be strongly opposed by the United States. Nonproliferation is defined by the DOD as the use of the full range of political, economic and military tools to prevent proliferation, to reverse it, or to protect the United States' interests against an opponent armed with WMD (3:1). As the policy developed, the Department of Defense's role in nonproliferation became known as counterproliferation.

Counterproliferation

Counterproliferation is a term used in the Defense Department which identifies the Department's role in countering the spread of weapons of mass destruction. It also refers to actions taken by the DOD to act against proliferation. The Defense Planning Guidance FY 95-99 states, "U.S. strategy will seek to prevent additional countries from acquiring WMD and, should our efforts fail, to deter, prevent, and defend against their use" (13:8). The actions taken by the U.S. to counter proliferation are only a part of the United States' nonproliferation policy.

The United States Air Force's definition of counterproliferation is based on four goals developed from the DOD's published counterproliferation policy. First, the DOD wishes to prevent countries from acquiring weapons of mass destruction and/or the means of delivering them. Second, it wants to deter WMD use against U.S. forces or those of our allies. Third, if deterrence should fail, the DOD would destroy WMDs prior to their use. Finally, the DOD would want to develop means by which the U.S. could reduce the military effectiveness of WMDs.

Each service has been tasked by the DOD to identify how the United States might be able to accomplish counterproliferation. Currently, the Joint Staff is trying to identify

systems which accomplish the counterproliferation objectives. There are many questions which the Air Force must answer. What systems could be used in a counterproliferation role? Are there any current systems/technologies which could be used in a counterproliferation role or that need improvement? Does the United States Air Force need to develop additional systems to meet the counterproliferation requirement? These questions take on increased significance when considering which systems to retain, develop or delete.

Problem Statement

Given the types of systems the military operates, the problem is to evaluate systems used to support the counterproliferation of WMD.

Research Objectives. A methodology which evaluates military systems used to support the counterproliferation of WMD is developed for the Air Staff's National Security Negotiations office (AF/XOXI). This methodology allows the Air Force to evaluate how systems support military counterproliferation objectives.

Systems which could be used in the accomplishment of the DOD's goals in counterproliferation are identified. A value function is developed to indicate the system's ability in accomplishing the DOD's counterproliferation mission. This value function is used to prioritize the alternative counterproliferation systems. The questions which must be asked in order to evaluate counterproliferation systems are identified. The model is flexible, so it can be modified to accurately reflect changes in the current view of counterproliferation or advances in the availability of new systems.

Approach. A value-focused approach is used to develop the model for evaluating counterproliferation alternatives. This approach creates a value model on the basis of qualities viewed as important in counterproliferation. The alternatives, in the case of this research, are the Air Force systems under evaluation for their contribution to counterproliferation.

The definition of counterproliferation is crucial to this research. Currently, there are many accepted definitions of counterproliferation. The U.S. Air Force's definition of counterproliferation, stated earlier, reflects the goals of the DOD's counterproliferation policy. Requirements are developed to accomplish these goals. Military systems which satisfy the requirements are identified and their quality is rated by AF/XOXI or by experts they select. A value function is developed to evaluate all the systems. The value function gives AF/XOXI the ability to evaluate the contribution of dissimilar military systems to counterproliferation.

This research develops an influence diagram model representing the United States' counterproliferation decision process. The U.S.'s current counterproliferation capability is defined. Perfect intelligence, perfect defensive and perfect offensive counterproliferation systems are evaluated to determine which type of system provides the greatest increase in the U.S.'s counterproliferation capability. A sensitivity analysis is performed on the counterproliferation model to identify key variables. All variables are screened to determine their sensitivity to perturbations in the model. Nine counterproliferation systems from the Vulcan's Forge 1995 wargame are evaluated to demonstrate how the model can be used to perform analysis of counterproliferation systems. A number of key questions are developed which must be answered in order to evaluate counterproliferation systems.

Overview

Chapter II presents the methodology to be used in the research. The chapter states the reason why decision analysis is used to evaluate systems for use in counterproliferation. Influence diagrams, which are the decision analysis technique used in evaluation of systems, are discussed. Value-focused thinking, the procedure used to create the influence diagram, is explained. Finally, the computer program DPL, which is the tool used to solve the counterproliferation influence diagram, is described.

Chapter III describes in detail the counterproliferation influence diagram. Each node within the diagram is identified and clearly defined.

Chapter IV reviews the results obtained from the model and analyzes them. Sensitivity analyses are presented and the behavior of the model is discussed. Some counterproliferation systems taken from the Vulcan's Forge 1995 system concept document are evaluated by the model to show the type of analysis that can be performed.

Chapter V summarizes the results of the research. Significant findings are presented and conclusions are drawn from the model. To aid future counterproliferation research, suggestions for follow-on study of the model are presented.

II. Methodology

Decision Analysis

A decision is considered hard if it contains many issues, great uncertainties, multiple competing objectives, and many differing opinions on the problem and its solutions (2:2). These factors make the evaluation of Air Force systems which support the Department of Defense's (DOD) policy on counterproliferation a very difficult and complex problem. Many issues are involved in counterproliferation. There are great uncertainties involved in identifying proliferators and determining when they will have WMD. The policy of counterproliferation has multiple objectives, and advancement of one objective might impede the achievement of another objective. Finally, there are many different opinions on counterproliferation and the systems which support it. Given this turbulent environment, evaluating Air Force systems for use in counterproliferation is a hard problem.

Decision analysis, a technique used to aid decision makers, is recommended for a hard problem of this kind (2:2). Decision analysis provides a framework for dealing with difficult decisions.

Decision analysis has two main methods for structuring decision problems: decision trees and influence diagrams. Decision trees show in great detail how a decision problem is constructed, but decision trees are difficult to interpret (2:54). Influence diagrams indicate the interdependency of uncertainties and better explain for senior managers the structure of a decision problem (2:55). The counterproliferation decision process is modeled using the influence diagram method.

Influence Diagrams. An influence diagram graphically represents a decision process (2:34; 6:719-762). The decisions, uncertainties, and values are connected together to show how each of the elements interact and influence each other. By using an

influence diagram, an analyst can identify the crucial decisions, indicate the key uncertainties affecting the decisions, and identify a value for the decision maker. The value is a measure of how well a decision maker's objectives are met.

The decisions, uncertainties and values in an influence diagram are represented by different shapes. These different shapes are shown in Figure 2.1. These general shapes are referred to as: decision nodes, chance/uncertainty nodes and value/deterministic nodes, respectively (2:34). Each node in an influence diagram is connected to other nodes through the use of directed arcs.

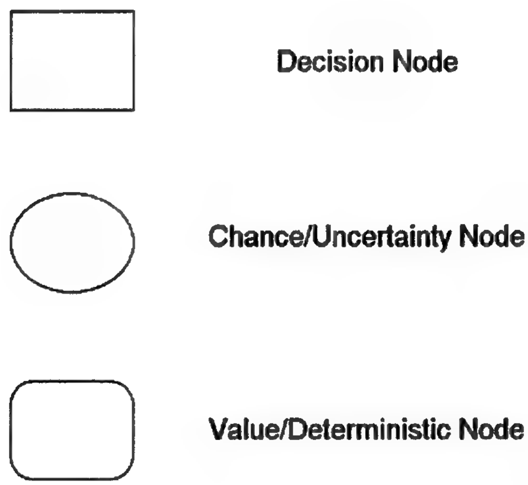

Figure 2.1 Influence Diagram Symbols

The directed arc in an influence diagram indicates that the outcome of the preceding node has some relevance on the outcome of the succeeding node. The definition of the influences represented by an arc going from one node to another are shown in Figure 2.2. For example, an arc from a chance node to a value node implies that the outcome of the value node depends on the outcome of the chance node. The influence diagram is constructed to capture the decision maker's current state of knowledge of the decision process (2:35).

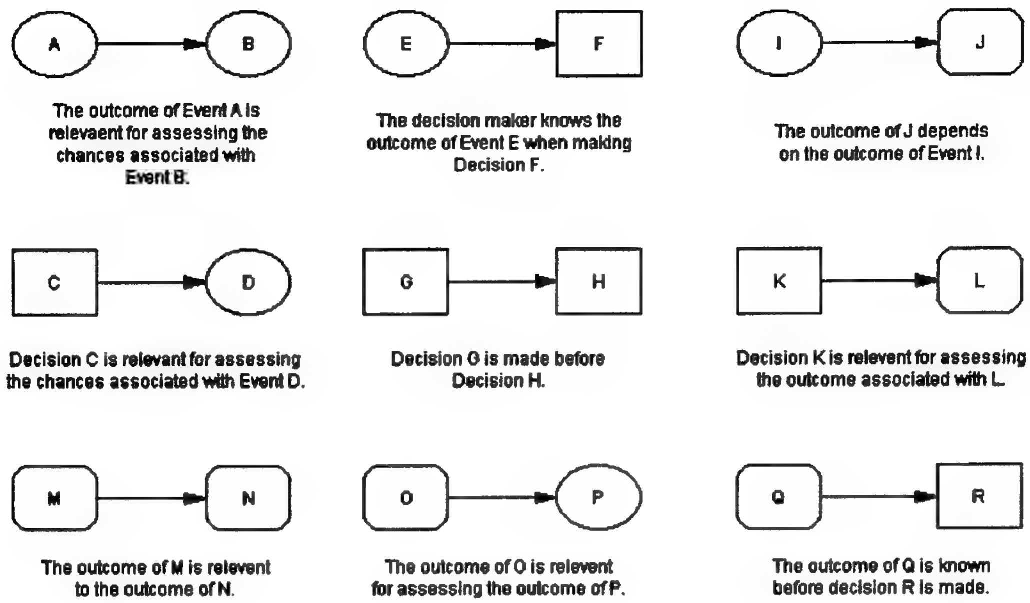

Figure 2.2 Influences Represented by Arcs

Another important construct used in this research is that of a conditioning node. In this research, a conditioning node is defined as a chance or decision node which is relevant to another node. The conditioning node's outcomes, known as conditioning states, are relevant to the outcome of the node it influences. Throughout the description of the counterproliferation influence diagram, an integral part of a node's definition is the conditioning nodes which influence its outcome.

A final important point about influence diagrams is that they are acyclic. In other words, there is no directed path which begins and terminates at the same node. Once a particular node is exited, there is no way to return to it. Prior to the development of the counterproliferation influence diagram, a discussion of pertinent decision analysis modeling techniques is presented.

Decision Analysis Modeling Techniques. In decision analysis, there are two main modeling techniques for examining a decision problem: alternative-focused thinking

and value-focused thinking (10:6). Both techniques use decision analysis methods to solve their problems. Alternative-focused thinking examines a problem's most obvious alternatives and models the decision problem based on the given alternatives. Value-focused thinking models a decision problem based on the values (objectives) the decision maker wants to accomplish.

The two techniques (alternative-focused thinking and value-focused thinking) achieve similar results, but their approaches are different. In alternative-focused thinking, viable alternatives not immediately obvious may be better than already identified alternatives. The objectives identified are often only the means to the consequences of fundamental concern, and there is no logical match between alternatives and objectives (10:44). Value-focused thinking, on the other hand, defines the objectives of the decision maker very carefully at the beginning of the modeling process. The model is then developed from these carefully defined objectives. A set of alternatives is then developed which accomplish these objectives. This approach allows the uncovering of hidden alternatives. Table 2.1 shows the process for both techniques. The two methods are similar, but it is obvious that alternative-focused thinking limits the decision maker to a certain set of alternatives. Value-focused thinking, on the other hand, allows the decision maker to determine what is important and then creates alternatives which accomplish the objectives.

With no clear set of alternatives available in the counterproliferation decision process, the value-focused thinking technique was used in this research to develop the counterproliferation influence diagram. Value-focused thinking provides an ability to identify the fundamental objectives of the DOD's counterproliferation policy. Before describing the counterproliferation model developed in this research, a discussion of the computer software used to solve the counterproliferation influence diagram is presented.

Table 2.1 Comparison of the Sequence of Activities for the Two Techniques(10:49)

Alternative-Focused Thinking for Decision Problems	Value-Focused Thinking for Decision Problems
1) Recognize a Decision Problem	1) Recognize a Decision Problem
2) Identify Alternatives	**2) Specify Values**
3) Specify Values	**3) Create Alternatives**
4) Evaluate Alternatives	4) Evaluate Alternatives
5) Select an Alternative	5) Select an Alternative

DPL

Using an influence diagram, the modeling technique of value-focused thinking is applied to the counterproliferation decision process. This influence diagram model of the counterproliferation process is solved by a computer package known as DPL. DPL, produced by ADA Decision Systems, solves decision analysis models such as the counterproliferation influence diagram produced in this research.

DPL solves decision analysis models in two phases: the roll forward and the rollback (4:30). DPL rolls forward by moving through the decision tree created by the influence diagram. Starting at the initial or root node, DPL moves through each path in the decision tree. This process results in a joint probability for each endpoint or final node evaluated, and a value is calculated for each endpoint or final node evaluated by the value model used in the influence diagram (4:30). A value model describes the state of the world under alternative scenarios (or alternative systems in the counterproliferation case) and indicates which state of the world a decision maker prefers (4:26).

Once DPL has rolled forward through the model, it then rolls back to determine the optimal decision for the initial decision node. The optimal expected value decision policy is the policy that maximizes the probability-weighed sum of the output of the model (4:31). The policy decisions are based on averages. If there are contingent decisions to

be made in the decision process, DPL will indicate the optimal contingent decision after any initial uncertainties are resolved. DPL therefore will be used to provide the means to evaluate the counterproliferation influence diagram given different counterproliferation systems.

Summary

The counterproliferation decision process is modeled using value-focused thinking and influence diagrams. The value-focused modeling technique is used to determine the fundamental objectives of the DOD's counterproliferation policy in order to model them in the counterproliferation influence diagram. DPL is used to evaluate the counterproliferation model assuming different systems, and a counterproliferation value for a system is derived based on the value determined by DPL. With an understanding of the techniques and methods used in modeling the counterproliferation decision process, the next chapter describes the influence diagram developed for this problem.

III. Counterproliferation Influence Diagram

This chapter discusses the model developed to represent the counterproliferation decision process. The model is presented as an influence diagram, and the influence diagram is shown in Figure 3.1. The model is broken into six areas; this facilitates defining each node in the influence diagram. Following the definition of the nodes is a discussion of the value model used in the influence diagram. In order to evaluate military systems, the counterproliferation process was modeled to determine each system's contribution to the accomplishment of the U.S.'s counterproliferation policy. The chapter begins with a discussion of the counterproliferation influence diagram.

The Counterproliferation Influence Diagram

The counterproliferation influence diagram is broken down into six areas for ease of explanation and comprehension. The six areas of the counterproliferation influence diagram are: the counterproliferation decisions, the intelligence systems' influence on the process, the political-military influences on the process, the offensive systems' influence on the process, the defensive systems' influence on the process, and the influences affecting the total counterproliferation value. The portion of the influence diagram pertaining to these areas is shown as each area is discussed. Those nodes relating to the nodes discussed in an area are shaded. In addition, a table pertaining to each area identifies each node type and name, the event represented by the node, the node's outcome, and the probability and value associated with each node. The value of the probabilities associated with one node are different from those shown for the other nodes. The table also lists the major conditioning node and conditioning states which are outcomes of the conditioning node affecting the node of interest. A conditioning node's outcome is relevant in determining the outcome of the node it affects.

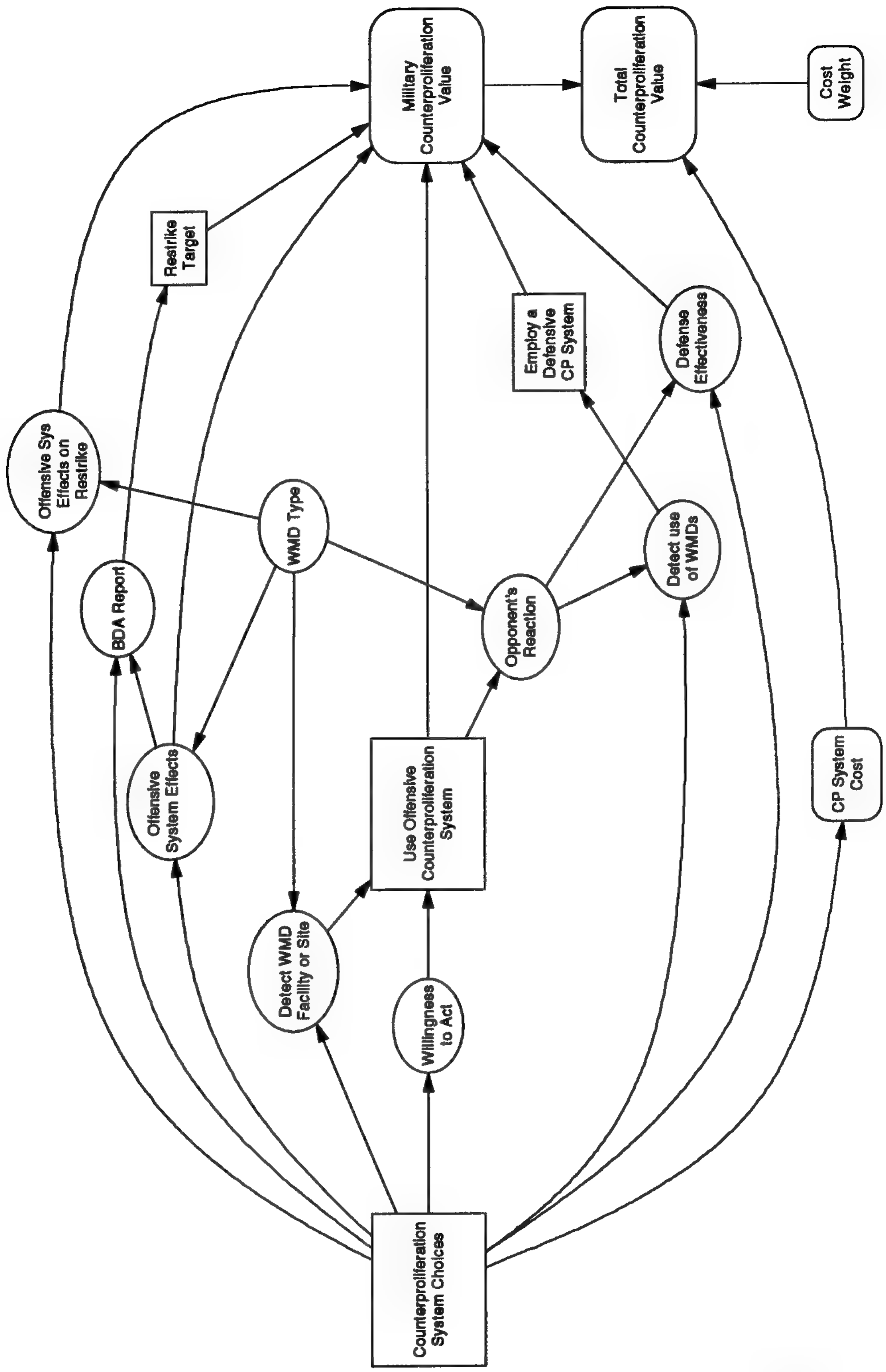

Figure 3.1 An Influence Diagram of the Counterproliferation Decision Process

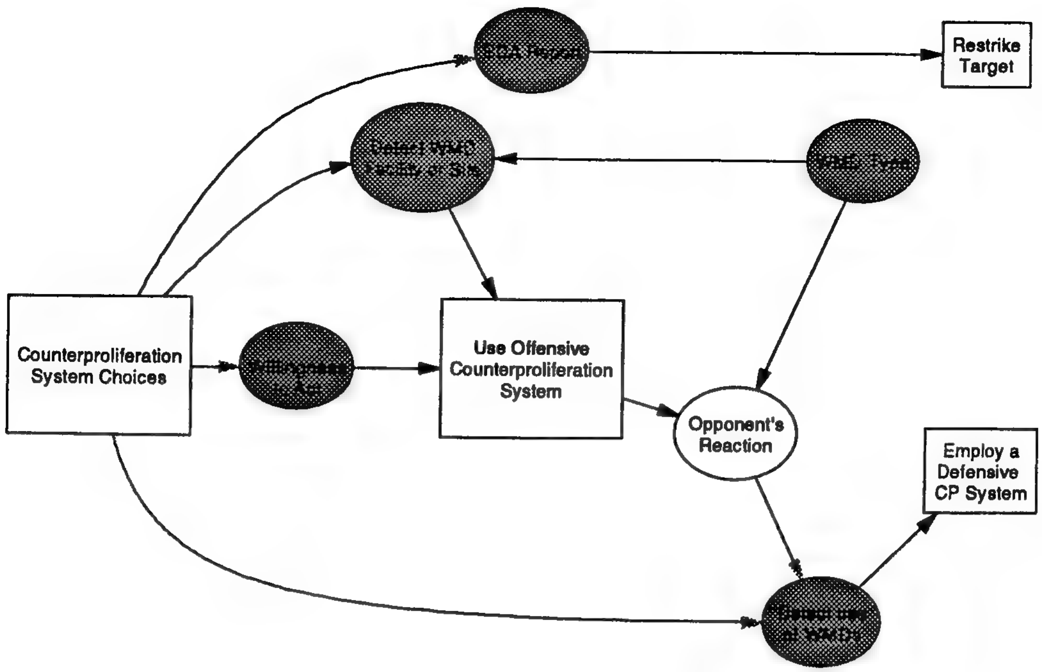

Figure 3.2 The Counterproliferation Decisions

The Counterproliferation Decisions. The basic decisions found in the counterproliferation decision area are shown in Figure 3.2. In this area, there is one decision made by our adversary, and there are four decisions which must be made by the United States. The adversary's decision is represented as a chance node because the United States is uncertain about an adversary's reaction to the United States' decision to use a counterproliferation system against the adversary. Each decision made by the United States is made in sequence, and the results of previous decisions are known before the next decision must be made. A list of the nodes and their definitions is contained in Table 3.1.

The first decision the U.S. faces is the *Counterproliferation System Choices* node. This node identifies the choices the United States has in approving a new counterproliferation system for research and development or remaining at the current counterproliferation systems capability level. The second decision faced by the U.S. in this process is *Use Offensive Counterproliferation System.* This decision indicates whether or not the U.S. attacks an adversary suspected of possessing WMD.

The next decision to be made in the process is made by the adversary. This decision is identified by the chance node labeled *Opponent's Reaction.* The *Opponent's Reaction* node identifies the probability that a country attacked by the United States in a counterproliferation attack will attack U.S. interests with WMD. The outcome of the *Opponent's Reaction* node influences the United States' decision to *Employ a Defensive CP System.*

The final two decisions in the counterproliferation decision area are identified by the nodes *Employ a Defensive CP System* and *Restrike Target. Employ a Defensive CP System* is a decision by the United States as to whether or not to use a defensive system in countering an opponent's WMD attack. The other decision is whether or not the United States should restrike the target. This decision is identified by the *Restrike Target* node.

Table 3.1 Counterproliferation Decision Node Definitions

Node Type:	Node Name:	Event:	Conditioning Node:	Conditioning States:	Outcome:	Prob:	Value:
Decision	Counterproliferation System Choices	Select a Counterproliferation System	None	None	Select a New System		
					Remain with Current Systems		
Decision	Use Offensive Counterproliferation System	Use an offensive CP system against a WMD site	Detect WMD Facility or Site and Willingness to Act	Yes/Yes	Yes		1
					No		0
				Yes/No or No/Yes	Yes		0
					No		0
				No/No	Yes		0
					No		0

Chance	Opponent's Reaction	Opponent retaliates against U.S. CP attack with a WMD attack against U.S. interests	WMD Type	NBC	Use Nuclear WMD	P1	1
					Use Chemical WMD	P2	1
					Use Biological WMD	P3	1
					Don't Use WMD	1-P1-P2-P3	0
				Chem/Bio	Use Nuclear WMD	0	0
					Use Chemical WMD	P1	1
					Use Biological WMD	P2	1
					Don't Use WMD	1-P1-P2	0
				Nuclear	Use Nuclear WMD	P1	1
					Use Chemical WMD	0	0
					Use Biological WMD	0	0
					Don't Use WMD	1-P1	0
				Nothing	Use Nuclear WMD	0	0
					Use Chemical WMD	0	0
					Use Biological WMD	0	0
					Don't Use WMD	1	0
Decision	Employ a Defensive CP System	Use a defensive system to stop an opponent's WMD attack	Detect Use of WMDs	Yes	Yes		1

					No		0
				No	Yes		0
					No		0
Decision	Restrike Target	Use an offensive CP system to attack a WMD site again	BDA Report	Report Kill	Yes		0
					No		0
				Report No Kill	Yes		1
					No		0

Intelligence System Influences to the CP Process. The most complicated set of influences are the intelligence system influences. The nodes of this area are shown in Figure 3.3. Table 3.2 defines the nodes that comprise the intelligence system influence area.

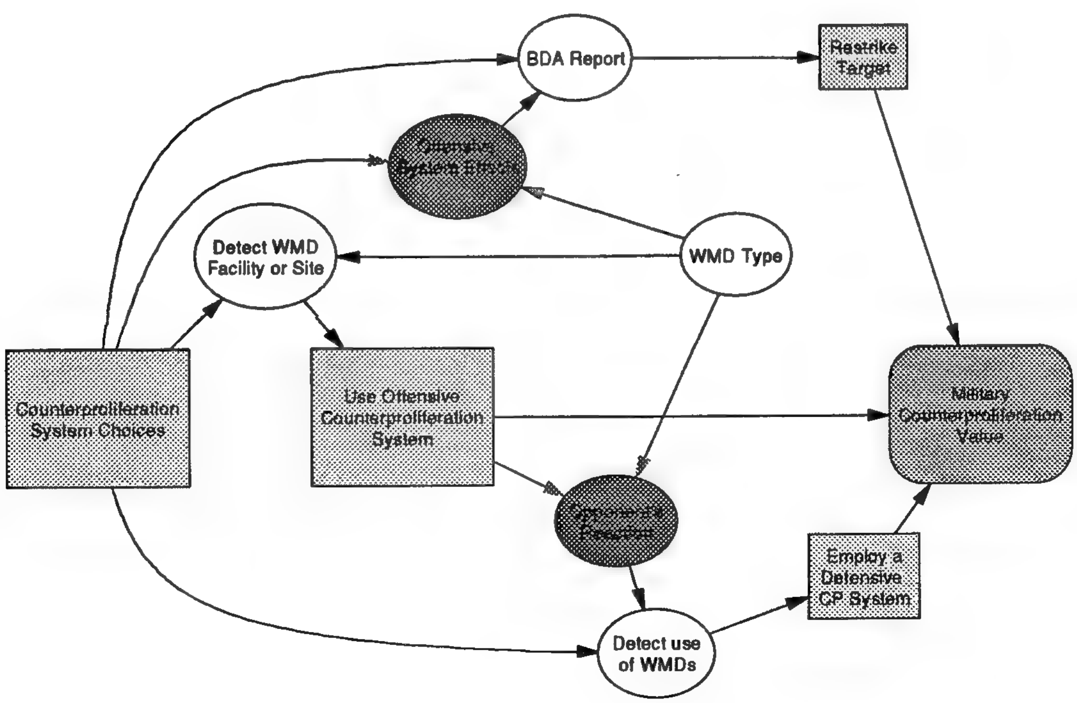

Figure 3.3 Intelligence System Influence on the Counterproliferation Process

Table 3.2 Intelligence System Node Definitions

Node Type:	Node Name:	Event:	Conditioning Node:	Conditioning States:	Outcome:	Prob:	Value:
Chance	WMD Type	Type of WMD possessed by an opponent	None	None	NBC	P1	1
					Chem/Bio	P2	1
					Nuclear	P3	1
					None	1-P1-P2-P3	0
Chance	Detect WMD Facility or Site (Strategic Warning)	Detect a WMD Facility or Site	WMD Type	NBC	Yes	P1	
					No	1-P1	
				Chem/Bio	Yes	P2	
					No	1-P2	
				Nuclear	Yes	P3	
					No	1-P3	
				None	Yes	P4	
					No	1-P4	
Chance	Detect Use of WMDs (Tactical Warning)	U.S. Detects release of a WMD by an adversary	Opponent's Reaction	Use Nuclear WMD	Yes	P1	
					No	1-P1	
				Use Chemical WMD	Yes	P2	
					No	1-P2	
				Use Biological WMD	Yes	P3	
					No	1-P3	

				Don't Use WMD	Yes	P4	
					No	1-P4	
Chance	BDA Report	A reported kill at a site struck by an offensive CP system	Offensive System Effects	Kill	Yes	P1	
					No	1-P1	
				No Kill	Yes	P2	
					No	1-P2	

The first node in the table, *WMD Type*, indicates the probability an adversary has the indicated combination of weapons of mass destruction. With nuclear, chemical and biological weapons, there are eight combinations of weapons possible including possessing none of the weapons. In order to simplify the influence diagram, the *WMD Type* node contains only four of the possible eight weapon combinations. The combinations selected are considered the most likely. This node is extremely important since it influences the U.S.'s ability to achieve strategic warning of WMDs through *Detect WMD Facility or Site*. In addition to influencing U.S. systems, *WMD Type* influences an adversary's ability to use WMD through *Opponent's Reaction.*

There are three intelligence system nodes in the influence diagram which model the U.S.'s intelligence capability. These nodes are strategic detection systems which aid offensive action - *Detect WMD Facility or Site*; tactical detection systems which aid defensive action - *Detect Use of WMD*; and intelligence system which report the results of an offensive action - *BDA Report.* The chance node *Detect WMD Facility or Site* indicates the U.S.'s ability to identify a nuclear, chemical, and/or biological site in an opponent's country prior to its use. *Detect WMD Facility or Site* influences the U.S.'s ability to attack this site since a site will not be attacked if it is not detected. The chance node *Detect Use of WMD* indicates the U.S.'s ability to detect the use of a WMD against interests of the United States.

The final intelligence system evaluated in the model is identified by the chance node *BDA Report*. *BDA Report* indicates the accuracy of Battle Damage Assessment reports coming from a WMD site attacked by the U.S. These reports are influenced by the effectiveness of the weapons system used to strike the site. This effectiveness is modeled in the *Offensive System Effects* chance node. *BDA Report* is available before the U.S.'s decision as to whether or not to restrike the target.

No intelligence system nodes have a direct influence on the *Military Counterproliferation Value*. However, intelligence systems are a major influence on decision nodes which do directly affect this value. These nodes include *Use Offensive Counterproliferation System*, *Employ a Defensive CP System*, and *Restrike Target* and are shown in Figure 3.3. Therefore, intelligence systems play a part in the determination of the counterproliferation value produced by this model. With the understanding that intelligence systems influence counterproliferation, an understanding of how political-military uncertainties can affect the process is necessary.

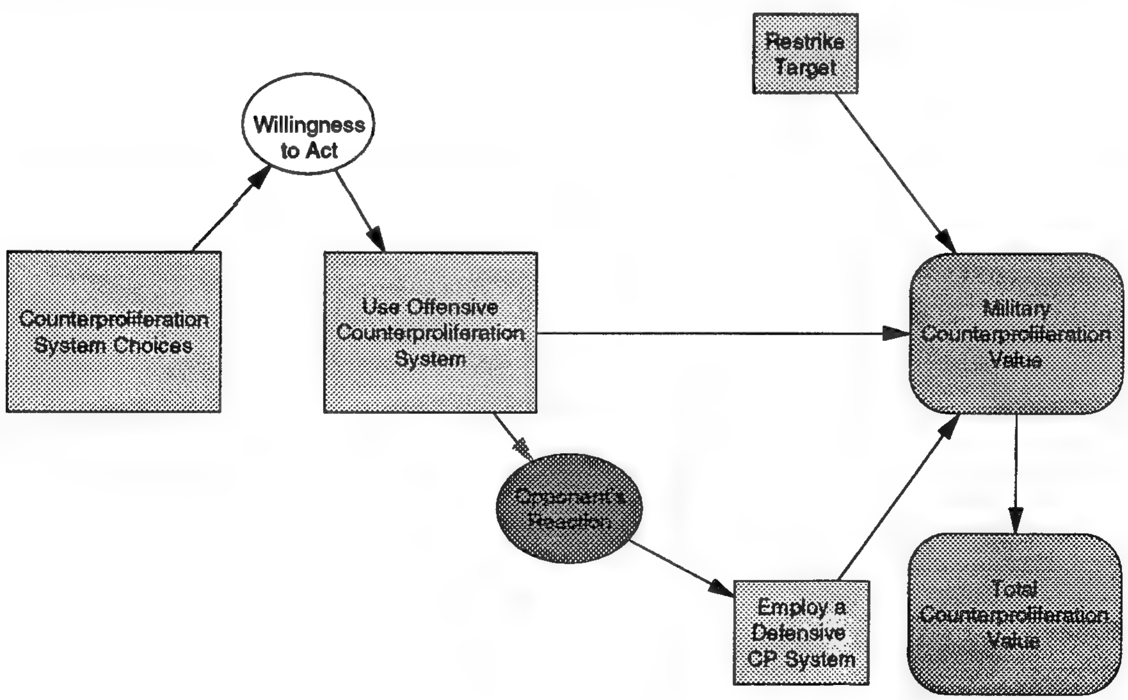

Figure 3.4 Political-Military Influences on the Counterproliferation Process

Political-Military Influences on the Process. The model developed in this research contains one node which represents the political-military influences in the counterproliferation process. This node is shown in Figure 3.4. The node is also defined in Table 3.3. *Willingness to Act* is the willingness of the U.S. government and public to support the use of an offensive weapon to strike a suspected WMD site. The outcomes of the *Willingness to Act* node depend on the choice of systems being considered. It is assumed that the probability of the public accepting the use of a defensive or intelligence system choice is 1.0. However, the probability of the public accepting the use of an offensive system against a WMD site might be less than 1.0. *Willingness to Act* influences the U.S.'s decision on whether or not to use an offensive counterproliferation system.

Offensive System Influences on the Process. Offensive systems are represented in the counterproliferation influence diagram by two chance nodes as shown in Figure 3.5. The *Offensive Systems Effects*, and *Offensive Sys Effects on Restrike* are defined in Table 3.4. The *Offensive System Effects* node indicates a system's ability to destroy a WMD site. The *Offensive System Effects* node's probabilities might be different for each *WMD Type* site attacked; however, it is assumed that these probabilities are all equal. *Offensive System Effects* influences the battle damage assessment report which influences the U.S.'s decision on whether or not to restrike the target.

Table 3.3 Political-Military Node Definition

Node Type:	Node Name:	Event:	Conditioning Node:	Conditioning States:	Outcome:	Prob:	Value:
Chance	Willingness to Act	U.S. public & government would accept an offensive CP strike against an opponent	CP System Choices	System i	Yes	Pi	
					No	1-Pi	

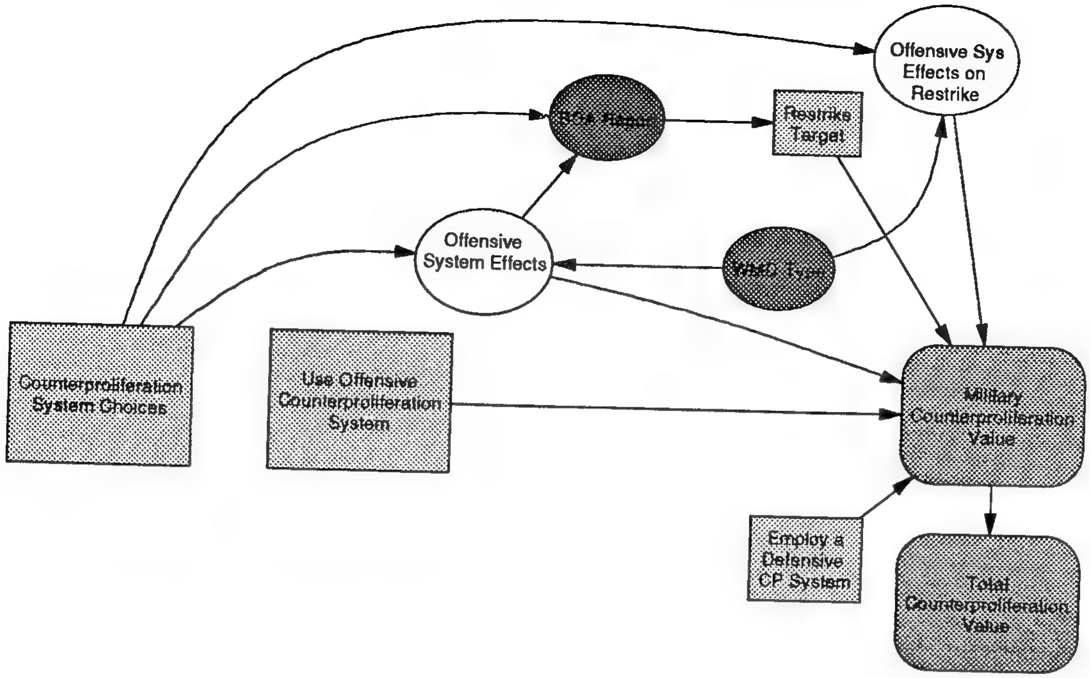

Figure 3.5 Offensive System Influences on the Counterproliferation Process

The final offensive system node is the *Offensive Sys Effects on Restrike* chance node. This node indicates the ability of an offensive system to kill a WMD site on a restrike of that site. It should be noted that the *Offensive Sys Effects on Restrike* node is not influenced by the *Restrike Target* decision node because the decision on whether or not to restrike a site does not affect a weapon's ability to destroy that site. The *Offensive Sys Effects on Restrike* node's probabilities of destroying a WMD site is assumed to be equal to those of the *Offensive System Effect*s node. *Offensive Sys Effects on Restrike* might be influenced by the type of WMD facility which must be struck; however, the probabilities for destroying the *WMD Type* sites are assumed to be the same.

Defensive System Influences to the Process. The defensive system influences on the counterproliferation process are shown in Figure 3.6. The definition of the defense system node is contained in Table 3.5. This process begins with the *Defense Effectiveness* chance node. This node indicates the probability of a defensive

Table 3.4 Offensive System Node Definitions

Node Type:	Node Name:	Event:	Conditioning Node:	Conditioning States:	Outcome:	Prob:	Value:
Chance	Offensive System Effects	Offensive Strike Destroys a WMD Site	WMD Type	NBC	Kill	P1	1
					No Kill	1-P1	0
				Chem/Bio	Kill	P2	1
					No Kill	1-P2	0
				Nuclear	Kill	P3	1
					No Kill	1-P3	0
				None	Kill	P4	0
					No Kill	1-P4	0
Chance	Offensive Sys Effects on Restrike	Offensive Restrike Destroys a WMD site	WMD Type	NBC	Kill	P1	1
					No Kill	1-P1	0
				Chem/Bio	Kill	P2	1
					No Kill	1-P2	0
				Nuclear	Kill	P3	1
					No Kill	1-P3	0
				None	Kill	P4	0
					No Kill	1-P4	0

Note: It is assumed that P1=P2=P3=P4.

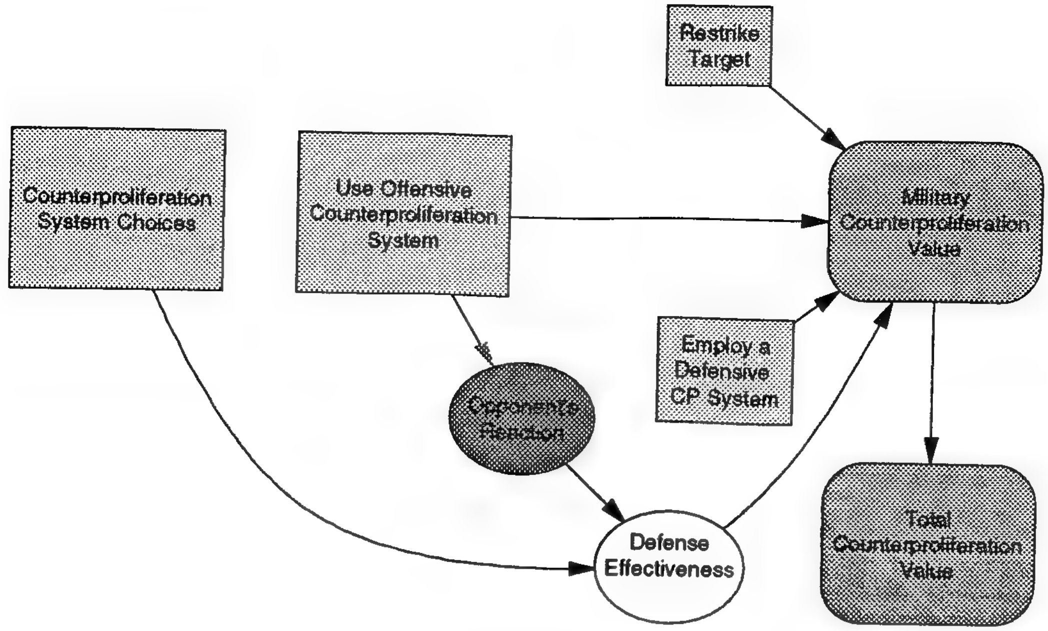

Figure 3.6 Defensive System Influences to the Counterproliferation Process

Table 3.5 Defense System Node Definition

Node Type:	Node Name:	Event:	Conditioning Node:	Conditioning States:	Outcome:	Prob:	Value:
Chance	Defense Effectiveness	Defeat the use of WMD by an Opponent	Opponent's Reaction	Use Nuclear WMD	Yes	P1	1
					No	1-P1	0
				Use Chemical WMD	Yes	P2	1
					No	1-P2	0
				Use Biological WMD	Yes	P3	1
					No	1-P3	0
				Don't Use WMD	Yes	1	0
					No	0	0

system defeating a nuclear, chemical, or biological attack, given that the attack is detected, with minimal loss of life. The *Opponent's Reaction* chance node influences the importance of each area of WMD defense in the *Defense Effectiveness* node. If a defensive system is not used and the United States is attacked with WMD by an opponent, the defense effectiveness is assumed to be zero.

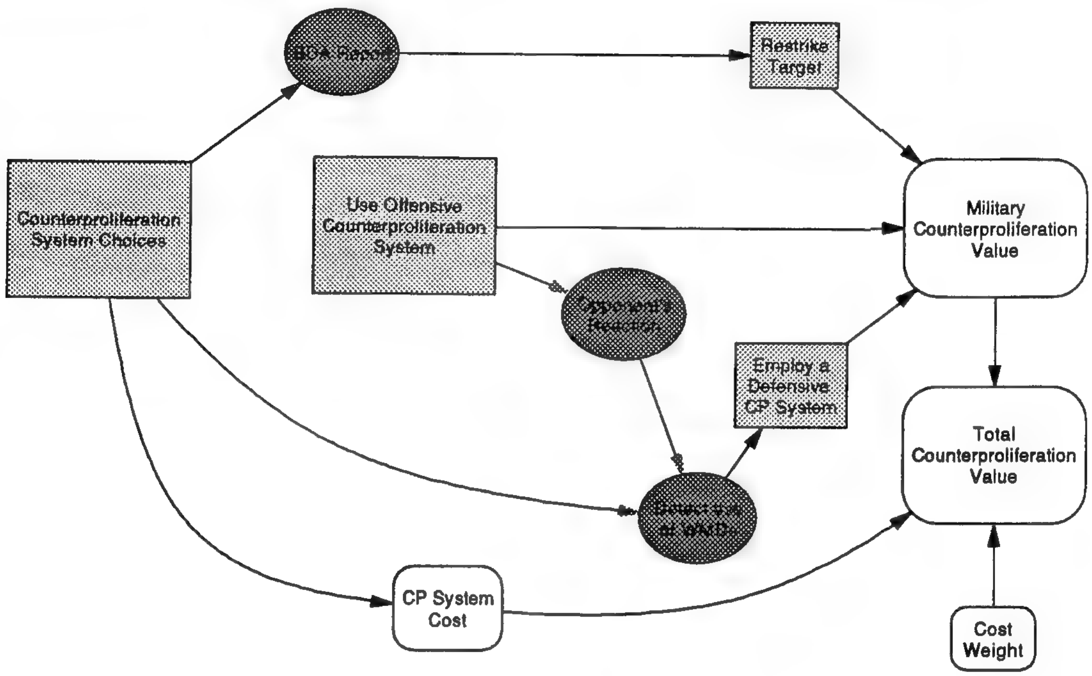

Figure 3.7 Influences on the Total Counterproliferation Value

Influences on the Total Counterproliferation Value. The final influences discussed are those which concern the *Total Counterproliferation Value* as shown in Figure 3.7. The definitions of the last nodes of concern in the counterproliferation influence diagram are shown in Table 3.6.

$$\text{Total Counterproliferation Value} = \text{Cost\_Weight} * \text{CP\_System\_Cost} + (1 - \text{Cost\_Weight}) * \text{Military\_Counterproliferation\_Value}$$

The *Total Counterproliferation Value* node is a value function which represents the military system's contribution to counterproliferation coupled with the budgetary considerations in acquiring a new counterproliferation system. The value function combines a budgetary value with the military effectiveness of a proposed system by using a weighting factor (*Cost Weight*). The *Cost Weight* is the relative importance of cost viewed in the total value of a counterproliferation system, and its value is between zero and one. The *Total Counterproliferation Value* node uses an "if " statement to produce a total counterproliferation value of zero when a military system has no military value.

The main influence added into the *Total Counterproliferation Value* node is *CP System Cost.* It is influenced by the *Counterproliferation System Choices* decision, and it is a linear utility function representing the cost of a counterproliferation system on a scale of zero to one (with zero representing the highest cost allowable and one representing a very low cost). The result of the value function is a system's counterproliferation value which combines its military effectiveness with its cost.

Military Counterproliferation Value =
Max((Defense_Effectiveness * Employ_a_Defensive_CP_System),
(Use_Offensive_CP_System * Max(Offensive_System_Effects,
Offensive_Sys_Effects_on_Restrike * Restrike_Target)))

The *Military Counterproliferation Value* node contains a value function which represents the military systems' contribution to counterproliferation. This function's value is the maximum of the offensive and defensive portions of the influence diagram. Decision trees detailing the results of the defensive portion of the *Military Counterproliferation Value* and the offensive portion of the *Military Counterproliferation Value* are shown in Appendix B.

The result of the *Military Counterproliferation Value* node is passed to the *Total Counterproliferation Value* node. As explained above, the *Military Counterproliferation*

Value is combined with a cost utility function for each alternative. This provides an evaluation of each system's counterproliferation effectiveness.

Table 3.6 Budgetary and Value Node Definitions

Node Type:	Node Name:	Event:	Conditioning Node:	Conditioning States:	Outcome:
Deterministic	CP System Cost	Cost Utility of a CP system	None	None	Between 0-1
Deterministic	Cost Weight	Relative importance of CP system cost in the counterproliferation decision process	None	None	Between 0-1
Deterministic	Military CP Value	Value of a counterproliferation system derived considering only military and political influences	None	None	Function
Value	Total CP Value	Value of a counterproliferation system derived considering a combination of military and budgetary influences	None	None	Function

IV. Analysis of the Counterproliferation Model Results

This chapter analyzes the results obtained from evaluating military systems using the counterproliferation influence diagram developed in this research. Initially, this chapter provides a description of the United States' base capability to accomplish its counterproliferation objectives. This base capability is called the current counterproliferation level in this research. Then, a description of how the model is used to evaluate different counterproliferation alternatives is presented. Next, the counterproliferation influence diagram is used to evaluate three alternatives: a perfect intelligence system, a perfect offensive system and a perfect defensive system. The results of this evaluation are discussed. In addition, a sensitivity analysis of the variables used in the model is made to determine which variable has the greatest effect on the model's results. Finally, nine proposed counterproliferation systems used in the Air Forces' wargame Vulcan's Forge 1995 are evaluated using the counterproliferation influence diagram model. The results are used to indicate how the model's output can be used to aid in the evaluation of counterproliferation systems.

Current Counterproliferation System Level

Due to the nature of this research, the current level of the U.S.'s counterproliferation systems is approximate. The notional probabilities used to represent the current counterproliferation level are shown in Table 4.1. They are used to establish the reasonableness of the model. It is assumed that for current U.S. offensive counterproliferation systems, the probability of the government and public supporting the use of the system against an adversary is one. The probabilities described are easily changed, so that the U.S. counterproliferation capability always contains current information.

Table 4.1 Notional Probabilities for U.S.'s Current Counterproliferation System

Node	Event	Prob:
Detect WMD Facility or Site	Probability of detecting a NBC facility	0.6
Detect WMD Facility or Site	Probability of detecting a Chemical or Biological facility	0.2
Detect WMD Facility or Site	Probability of detecting a Nuclear facility	0.5
Offensive System Effects	Probability of destroying a WMD facility	0.85
Offensive Sys Effects on Restrike	Probability of destroying a WMD facility	0.85
BDA Report	Probability of Reporting a site destroyed given that it is destroyed	0.6
BDA Report	Probability of Reporting a site destroyed given that it is not destroyed	0.2
Detect Use of WMD	Probability of detecting a Nuc attack	0.6
Detect Use of WMD	Probability of detecting a Chem attack	0.2
Detect Use of WMD	Probability of detecting a Bio attack	0.2
Defense Effectiveness	Probability of neutralizing a Nuc attack	0.5
Defense Effectiveness	Probability of neutralizing a Chem attack	0.1
Defense Effectiveness	Probability of neutralizing a Bio attack	0.1
WMD Type	Probability of a country having a NBC facility	0.33
WMD Type	Probability of a country having a Chem/Bio facility	0.33
WMD Type	Probability of a country having a Nuclear facility	0.33
Opponent's Reaction (Opponent has NBC Facility)	Probability an opponent would attack with Nuclear WMD	0.33
Opponent's Reaction (Opponent has NBC Facility)	Probability an opponent would attack with Chemical WMD	0.33
Opponent's Reaction (Opponent has NBC Facility)	Probability an opponent would attack with Biological WMD	0.33
Opponent's Reaction (Opponent has Chem/Bio Facility)	Probability an opponent would attack with Chemical WMD	0.5
Opponent's Reaction (Opponent has Chem/Bio Facility)	Probability an opponent would attack with Biological WMD	0.5
Opponent's Reaction (Opponent has Nuclear Facility)	Probability an opponent would attack with Nuclear WMD	1.0

System Evaluation

This section describes the information and procedures required to evaluate a counterproliferation system alternative. Each current level system probability is defined in a deterministic node located above the influence diagram in DPL. These nodes are identified as *Baseline* (probability type description). For example, the probability of detecting a chemical or biological facility or site is defined in the deterministic node *Baseline Prob Detecting Chem\Bio Site*. These baseline nodes can be edited to update changes. The system alternative to be evaluated must be added to the *Counterproliferation System Choices* decision node. Of the thirteen probabilities listed in Table 4.1, those effected by the new counterproliferation system must be determined and the model inputs updated. When the influence diagram is solved by DPL, the new system alternative's counterproliferation value is obtained.

There are a number of questions which should be asked in determining the ability of a new counterproliferation system. These questions include what type of system is being evaluated: offensive, defensive, intelligence or some combination of the three. The type of system determines which nodes are effected. An offensive system effects the *Offensive System Effects* and *Offensive Sys Effects on Restrike* nodes; a defensive system effects the *Defensive Effectiveness* node; and an intelligence system effects the *Detect WMD Facility or Site*, *Detect Use of WMDs* and/or *BDA Report* nodes. It is very important to give proper credit so the new system can receive a fair evaluation. Once the effected node(s) are identified, it must be determined either how much more effective the new counterproliferation system is than what is currently possessed by the U.S. or what is the probability of the event represented by the effected node. The cost utility of the new system should be determined and the level of technological challenge required to produce the new system should also be determined.

Perfect Systems

The first systems evaluated in the counterproliferation model are perfect systems. In this research, a perfect system is defined as one which has a probability of one of accomplishing its mission. A perfect offensive system destroys a WMD facility or site with a probability of one. A perfect defensive system neutralizes a nuclear, chemical or biological attack with a probability of one. A perfect intelligence system detects a WMD facility or site, detects the use of nuclear, chemical and biological weapons and correctly reports the battle damage received by a WMD site with a probability of one. In evaluating perfect systems, the model shows which type of system is most valuable in accomplishing the U.S.'s counterproliferation objectives.

In this section, the U.S.'s current counterproliferation systems were evaluated with perfect offensive, perfect defensive, or perfect intelligence counterproliferation systems incorporated, and the results are shown in Table 4.2. The results indicate that a perfect intelligence system is preferred to all other alternatives. The cumulative distribution function (CDF) describing this result is shown in Figure 4.1. The CDFs indicate that a perfect intelligence system is stochastically dominant meaning that no matter what variation occurs in the model, a perfect intelligence system is preferred to any other perfect system evaluated in Table 4.2. This result makes sense because our current

Table 4.2 Results of Perfect Counterproliferation System Evaluation

Alternative Evaluated	Military Counterproliferation Value
Current System Level	0.48
Perfect Offense	0.50
Perfect Defense	0.62
Perfect Intelligence	0.98
Perfect Detection of WMD Facility (Perfect Intell Offense)	0.96
Perfect Detection of WMD Use (Perfect Intell Defense)	0.56
Perfect BDA (Perfect Intell BDA)	0.49

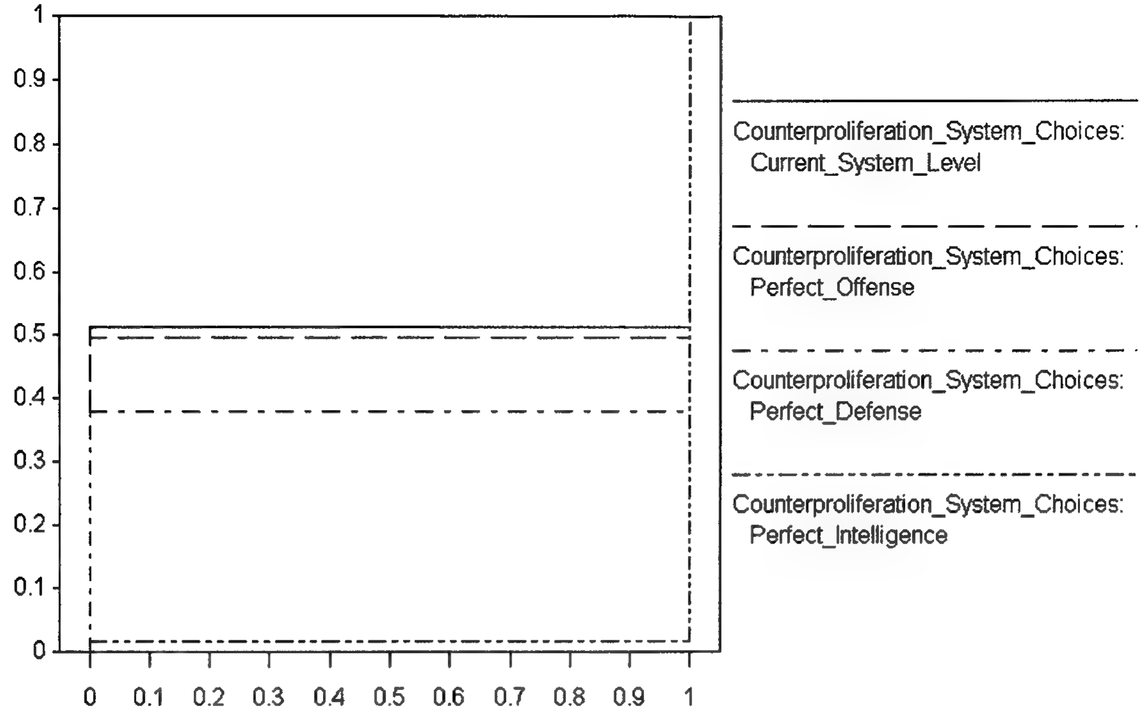

Figure 4.1 CDF of Perfect Systems Evaluation

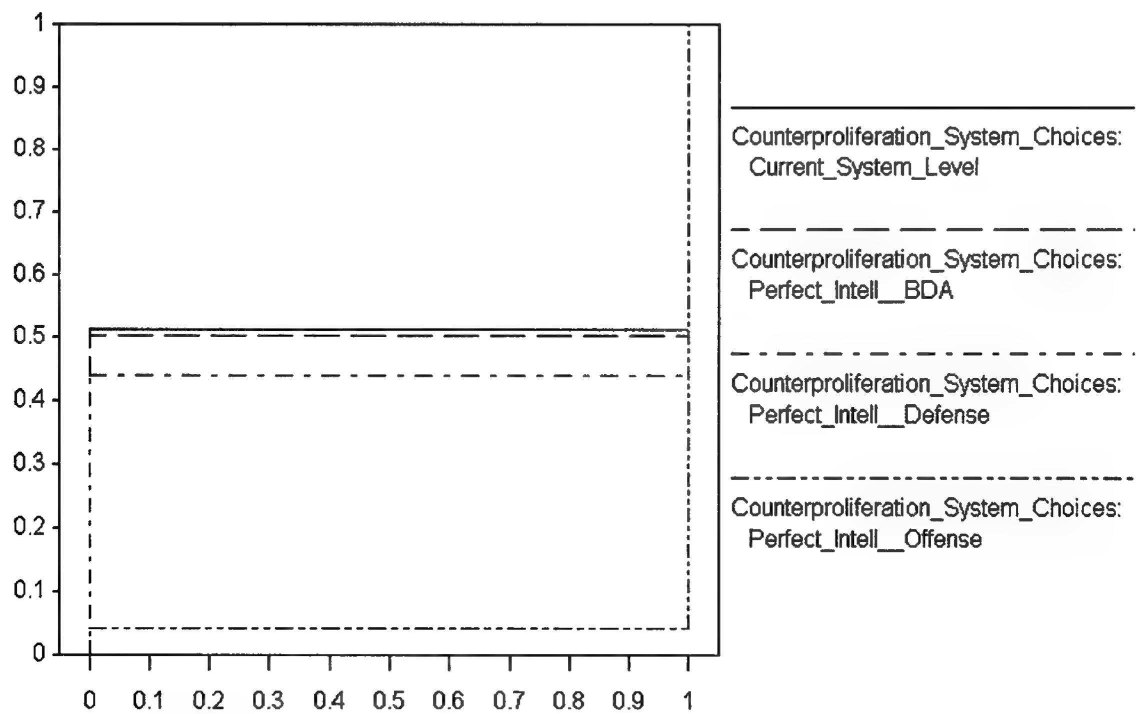

Figure 4.2 CDF of Perfect Intelligence Systems Evaluation

offensive capability is very good, and intelligence systems are required for both offensive and defensive systems to be used.

Since a perfect intelligence system is the preferred alternative, we next examined which type of intelligence system is the most valuable. To do this, three perfect intelligence systems were separately evaluated: a perfect WMD facility or site detection system (Perfect Intell Offense), a perfect WMD use detection system (Perfect Intell Defense), and a perfect BDA system (Perfect Intell BDA). The results of this evaluation are shown in Table 4.2. The results indicate that a perfect WMD facility detection system is the preferred alternative. In addition, Figure 4.2 indicates that a perfect WMD facility detection system is stochastically dominant. This indicates that the U.S. should strongly consider concentrating its efforts on building intelligence systems which detect WMD facilities.

Since the same model was used to evaluate the systems in Table 4.2, the values of the alternatives can be compared. A perfect intelligence system is the preferred system, followed by a perfect WMD Facility detection system, a perfect defensive system, a perfect WMD use detection system, a perfect offensive system and a perfect BDA system. These results show that intelligence and defensive systems provide the most value to the U.S.'s counterproliferation policy while perfect offense provides little value. The reason for this is the weakness of current U.S. intelligence systems and defensive systems and the strength of current U.S. offensive systems. These results highlight some interesting points, but the sensitivity of the counterproliferation values to changes in the baseline factors which comprise the value must be examined.

Sensitivity Analysis

The purpose of sensitivity analysis is to determine the most important variables in a model and to simplify the problem structure. Tornado and rainbow diagrams are decision analysis techniques used to perform sensitivity analysis. A tornado diagram graphically

indicates how the variation in a number of factors evaluated one factor at a time impact the value of an alternative (2:116). A bar representation of the change in an alternative for each varied factor is plotted on the diagram. A rainbow diagram graphically indicates how the value of an alternative changes with the variation of only one factor. A line graph is used to represent the change in the alternative's value versus a change in the factor being investigated.

The first four tornado diagrams examine how changes in military capability parameters effect the alternatives of perfect intelligence, perfect defense, perfect offense and current system level. The tornado diagrams detailing these effects are shown in Figure 4.3, Figure 4.4, Figure 4.5, and Figure 4.6. The military capabilities changed are

Table 4.3 Variation in Model Factors Used in Sensitivity Analysis

Node	Low Value	Base Value	High Value
Detect WMD Facility or Site (NBC site)	0.4	0.6	0.8
Detect WMD Facility or Site (Chem/Bio site)	0	0.2	0.4
Detect WMD Facility or Site (Nuclear site)	0.3	0.5	0.7
Offensive System Effects	0.7	0.85	1
Offensive Sys Effects on Restrike	0.7	0.85	1
BDA Report (Site destroyed on first strike)	0.4	0.6	0.8
BDA Report (Site not destroyed on first strike)	0	0.2	0.4
Detect Use of WMD (Nuclear)	0.4	0.6	0.8
Detect Use of WMD (Chemical)	0	0.2	0.4
Detect Use of WMD (Biological)	0	0.2	0.4
Defense Effectiveness (Nuclear)	0.3	0.5	0.7
Defense Effectiveness (Chemical)	0	0.1	0.3
Defense Effectiveness (Biological)	0	0.1	0.3
WMD Type (NBC)	0	0.333	1
WMD Type (Chem\Bio)	0	0.333	1
WMD Type (Nuclear)	0	0.333	1
Opponent's Reaction NBC (Nuclear varied)	0	0.333	1
Opponent's Reaction NBC (Chemical varied)	0	0.333	1
Opponent's Reaction NBC (Biological Varied)	0	0.333	1
Opponent's Reaction Chem/Bio	0	0.5	1
Opponent's Reaction Nuclear	0	1	1

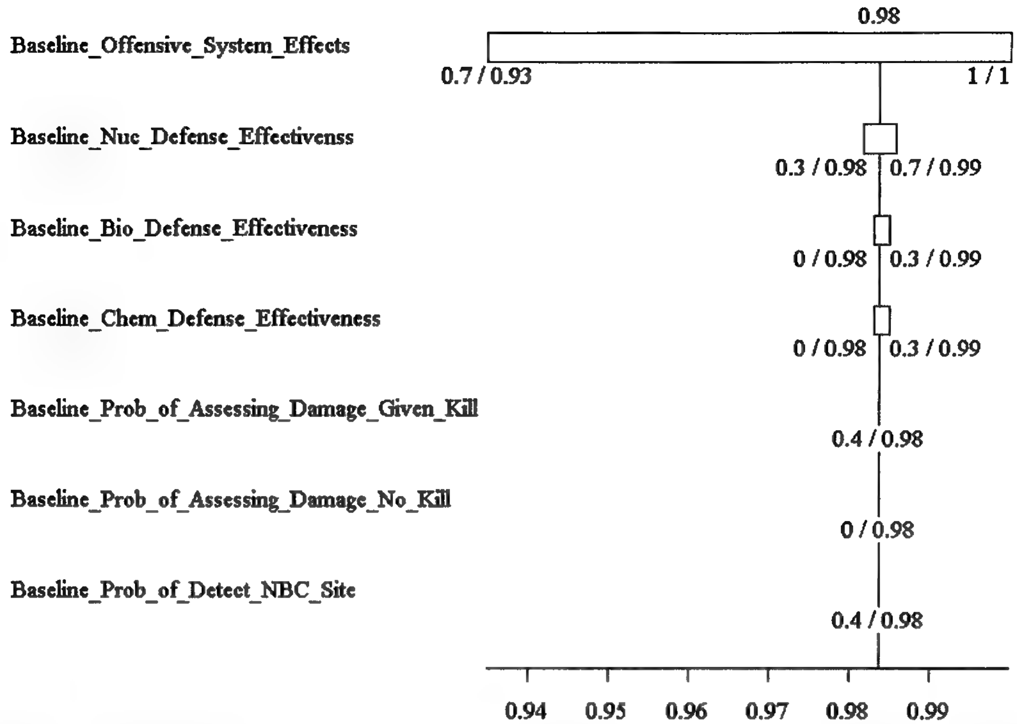

Figure 4.3 Military Capability Tornado Diagram Indicating Changes in Perfect Intelligence

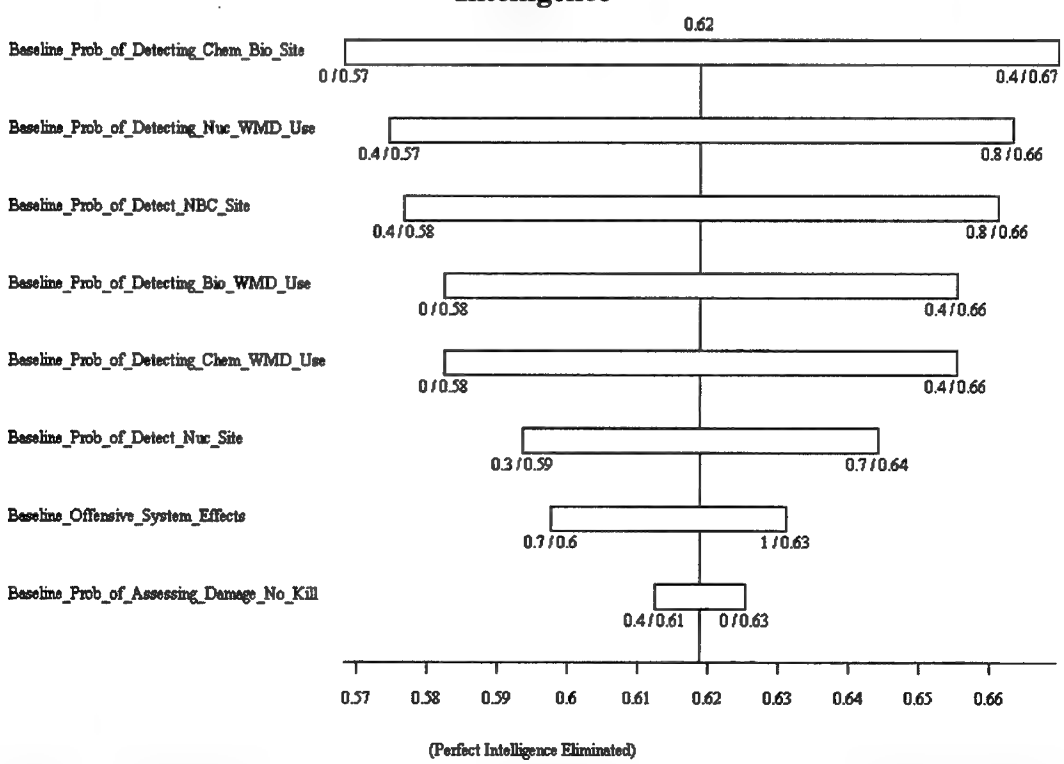

Figure 4.4 Military Capability Tornado Diagram Indicating Changes in Perfect Defense

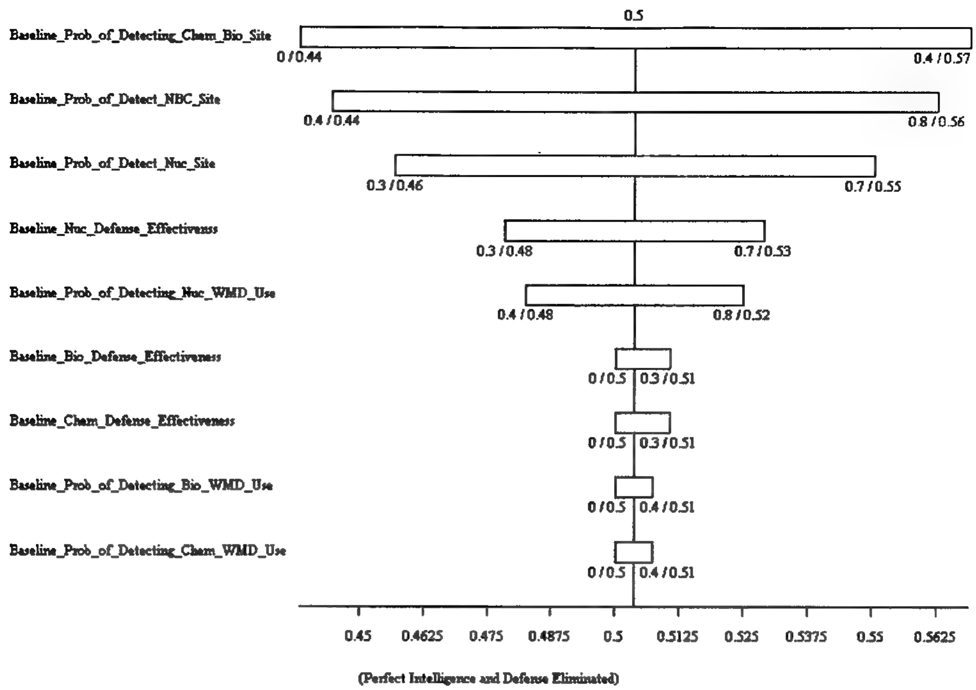

Figure 4.5 Military Capability Tornado Diagram Indicating Changes in Perfect Offense

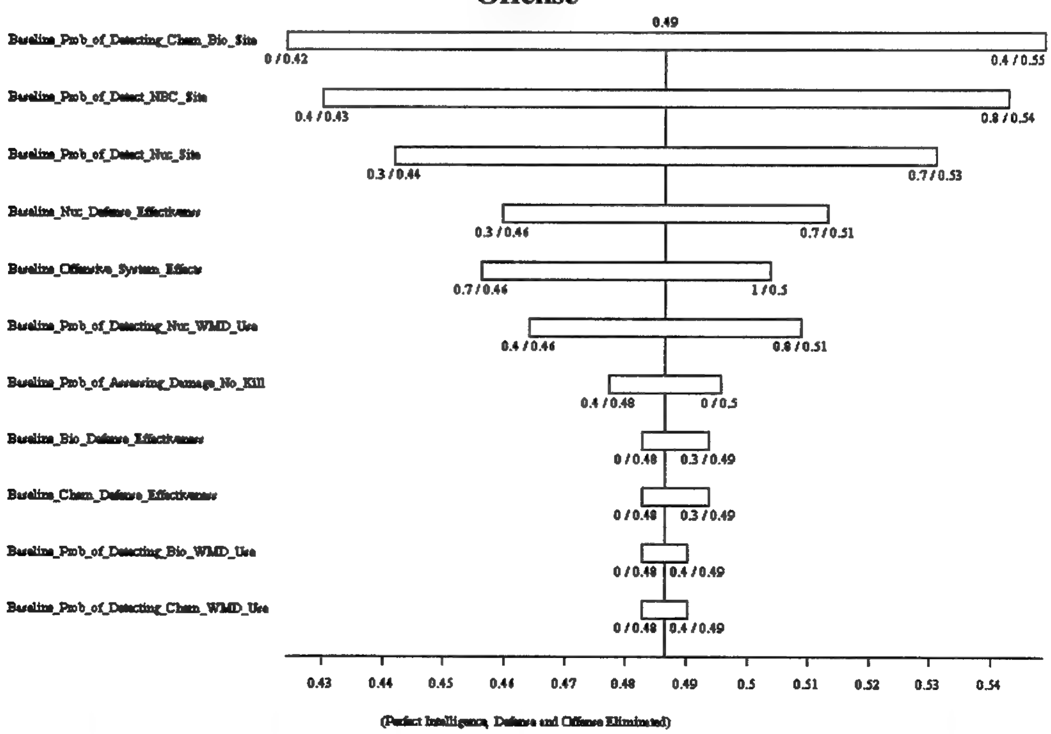

Figure 4.6 Military Capability Tornado Diagram Indicating Changes in Current Counterproliferation Level

the three baseline probabilities for detecting a WMD facility or site, the three baseline probabilities for detecting the use of a WMD, the two baseline probabilities for battle damage assessment, the baseline probability of offensive system effectiveness, the baseline probability of offensive system effectiveness on restrike, and the three baseline probabilities for defensive system effectiveness. The range over which each military capability probability is varied is shown in Table 4.3. In addition, the changes made to the *WMD Type* and *Opponent's Reaction* nodes' probabilities are shown in Table 4.3. Despite changes in these factors, the preferred alternatives of the perfect systems remain the same. Varying military capability parameters does not change these preferences. The three probabilities associated with the ability to detect a WMD facility caused the most variation in the perfect defense, perfect offense and current level counterproliferation value when allowed to vary by plus or minus 0.2. The alternatives vary in counterproliferation value by approximately 0.1. For perfect intelligence, the variance in baseline offensive system effects is the most important variable. It causes the counterproliferation value to vary by 0.07. The tornado diagrams indicate that though each alternative's counterproliferation value may change, the relative importance of the alternatives are relatively insensitive to changes in the probabilities.

A rainbow diagram was used to examine the changes resulting from variations in the probability used in the *Willingness to Act* chance node. Figure 4.7 shows how changes in the willingness to act probability affect the alternative of perfect offense. Willingness to act has no effect on the counterproliferation value of perfect intelligence or defense. Figure 4.7 indicates that if the willingness to act with an offensive weapon is below 0.96, the weapon's counterproliferation value falls below the U.S.'s current counterproliferation system value. Therefore, the government's and the public's willingness to use an offensive system must be close to one; otherwise, the offensive system should not even be evaluated.

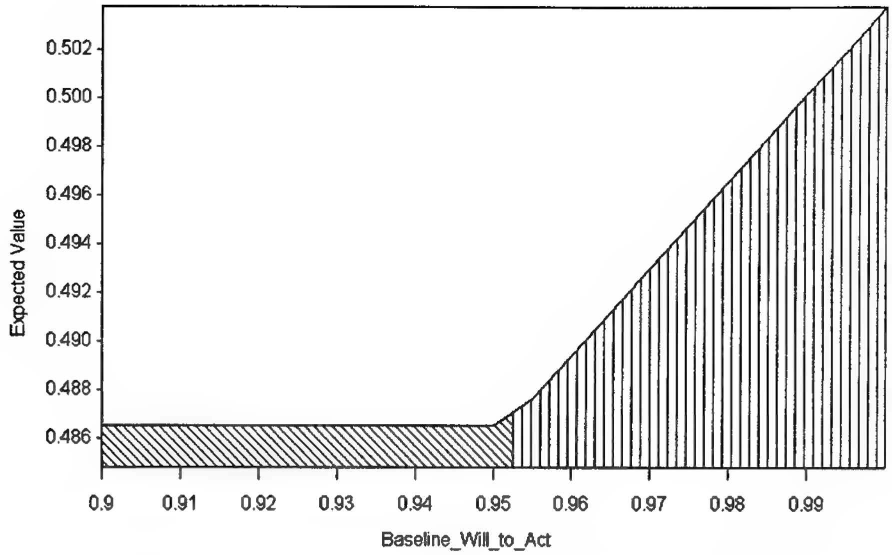

Figure 4.7 Rainbow Diagram of Changes in Perfect Offense

The final four tornado diagrams investigate the result of changes in nodes which model the opponent's influence. These nodes are *WMD Type* and *Opponent's Reaction.* Figure 4.8, Figure 4.9, Figure 4.10, and Figure 4.11 illustrate the result of changes in the probabilities in the *WMD Type* and *Opponent's Reaction* nodes. Again, as in the previous tornado diagrams, the changes in the probabilities (which were varied from zero to one in all cases) never changed the preference for the perfect alternatives. A perfect intelligence system was preferred to a perfect defensive system which was preferred to a perfect offensive system. The greatest changes in the counterproliferation value resulted from variations in the WMD Type node by varying the probability of either a nuclear site, a chemical/biological site or a NBC site since the U.S. does not have an effective capability for detecting or defeating chemical and biological weapons. The tornado diagrams again show the impact of the U.S.'s low capability in defeating chemical and biological attacks. Whenever the probabilities in the *WMD Type* and *Opponent's Reaction* nodes indicate that an opponent has a greater chance of having chemical or biological weapons, the counterproliferation value for the alternatives being evaluated are smaller than when the chance is greater that an opponent has nuclear weapons. *WMD Type* and *Opponent's*

Reaction nodes have a none and no attack state, respectively. By including probabilities for these states, the military counterproliferation value is only made smaller, obscuring the true military counterproliferation value of a system.

Changing the opponent's nodes does not effect the preferred results; however, the none in the *WMD Type* and no attack states in the *Opponent's Reaction* node only lessen the military counterproliferation value for all alternatives. Therefore, the probabilities of the none and no attack states should be set to be zero. Finally, for analysis purposes, *WMD Type* should probably be set to 0.333 for each outcome: NBC, Chem/Bio, and Nuclear. This allows a fair analysis of the U.S.'s abilities against each outcome. The opponent should always react in the *Opponent's Reaction* node; otherwise, the military counterproliferation value is artificially lowered. The sensitivity analysis reveals that changes in the baseline probabilities used to describe the current U.S. capability do not alter the perfect system preferences.

Vulcan's Forge System Analysis

The counterproliferation model developed in this research can be used to conduct analysis of competing counterproliferation systems. Nine counterproliferation systems are selected from the Vulcan's Forge 1995 System Concepts documentation for evaluation by the counterproliferation model. All values concerning Vulcan's Forge systems are notional. Appendix A identifies and defines the nine systems which are evaluated. The inputs for the systems used in the counterproliferation influence diagram were developed through conversations with the points of contact for the counterproliferation system and are also contained in Appendix A. The results of the evaluations of the Vulcan's Forge systems provided by the counterproliferation influence diagram are shown in Table 4.4.

Figure 4.8 Tornado Diagram of Opponent's Node Changes on Perfect Intelligence

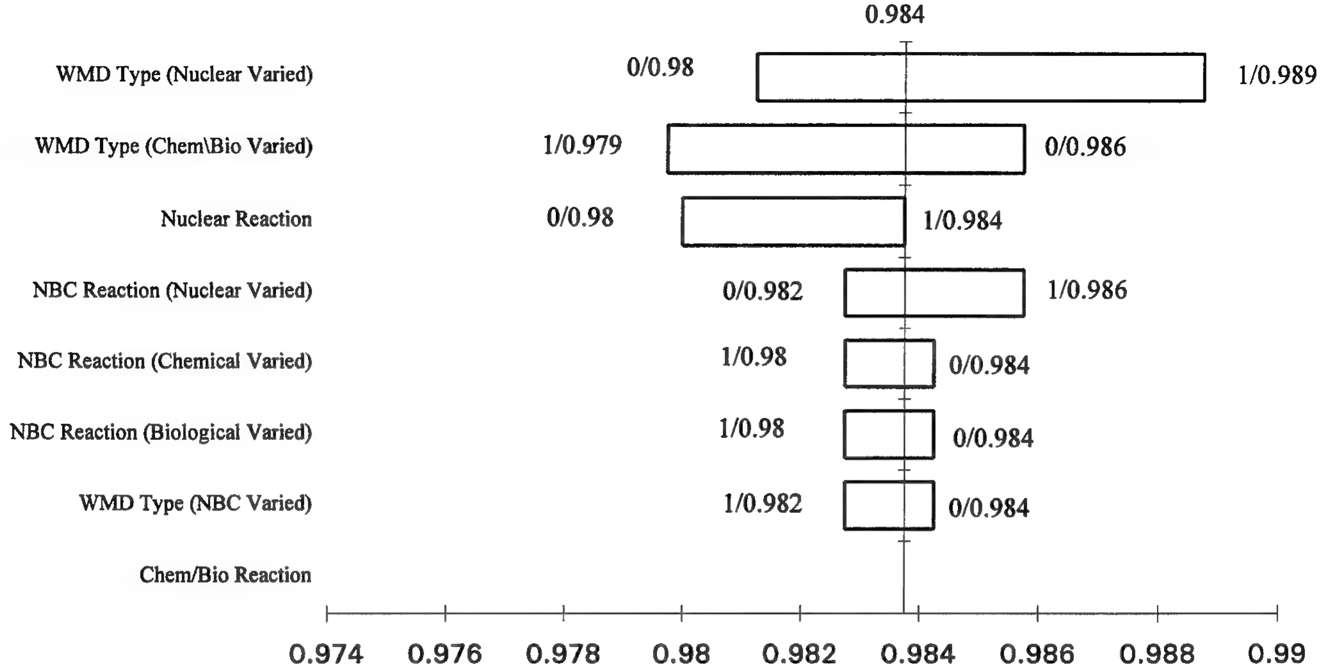

Figure 4.9 Tornado Diagram of Opponent's Node Changes on Perfect Defense

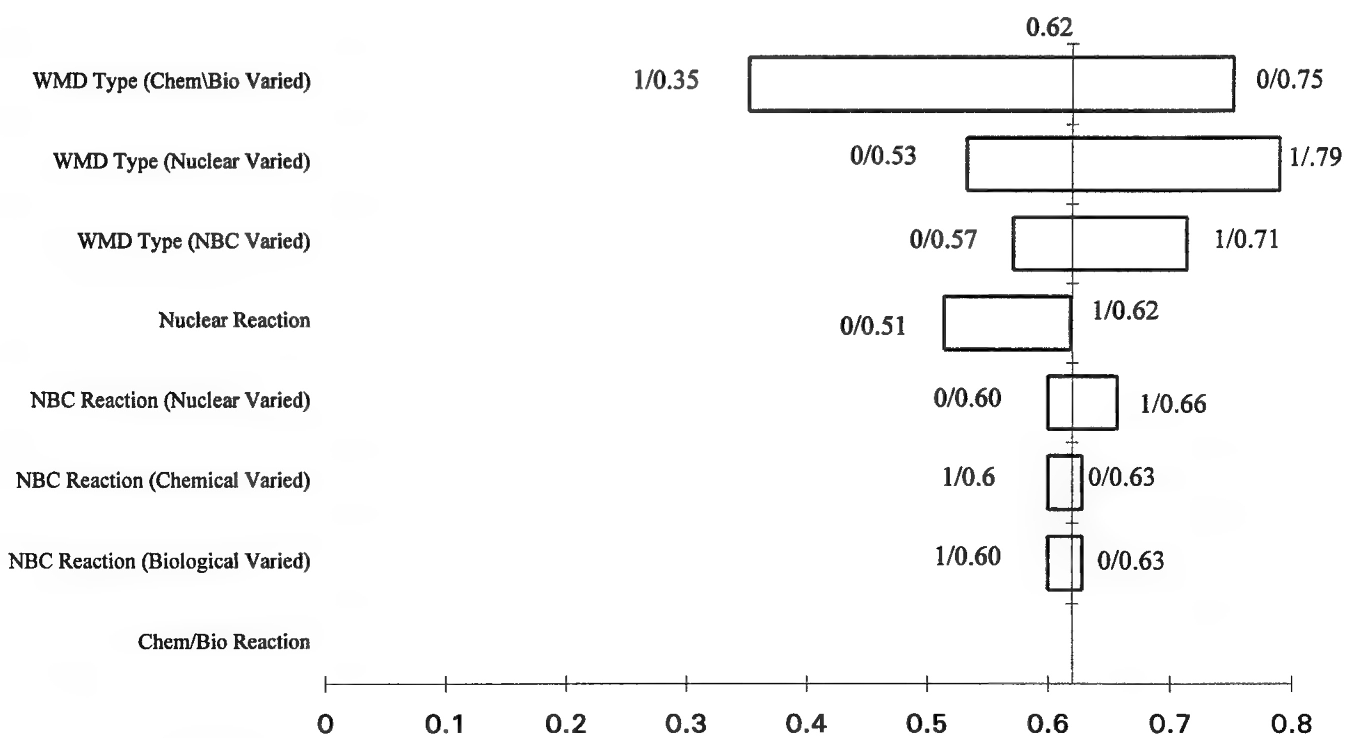

Figure 4.10 Tornado Diagram of Opponent's Node Changes on Perfect Offense

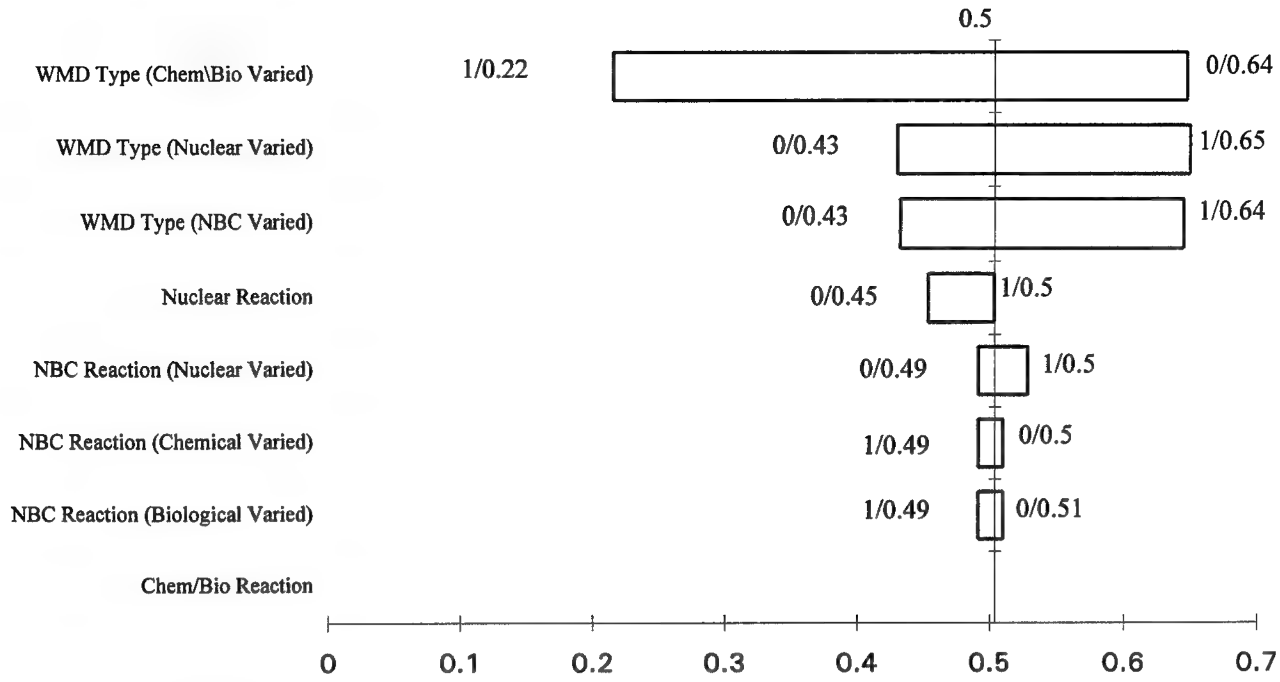

Figure 4.11 Tornado Diagram of Opponent's Node Changes on Current Counterpoliferation System Level

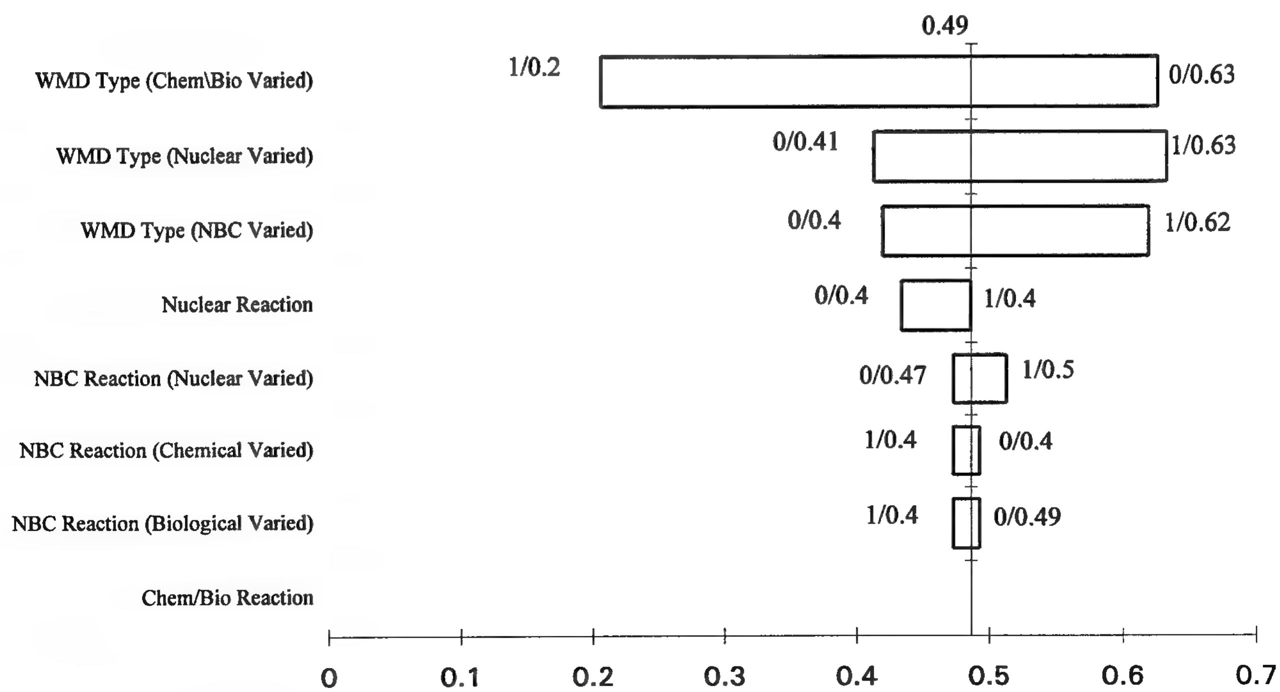

Table 4.4 Vulcan's Forge System Counterproliferation Value

System Evaluated	Military Counterproliferation Value	Total Counterproliferation Value
RF weapon and SCUD mine	0.49	0.53
Hypervelocity KE Weapon	0.50	0.60
Conventional ICBM	0.50	0.67
Modular NBC Ensemble	0.54	0.53
Advanced Airborne Laser	0.53	0.55
ARC SPEAR	0.78	0.52
Global Eyes	0.64	0.56
Gravimetric Reconnaissance	0.61	0.44
On-Demand Tactical Satellite	0.66	0.47

The military counterproliferation values show that ARC SPEAR is best, followed by On-Demand Tactical Satellite, Global Eyes, and Gravimetric Reconnaissance. All four of these systems provide some increased intelligence capability, which further demonstrates that intelligence systems provide the greatest increase in the U.S.'s ability to accomplish its counterproliferation objectives.

The total counterproliferation value column in Table 4.4 combines estimates of the costs of each system with the military counterproliferation value. In this case, the military counterproliferation value is set to be twice as important as the system cost; therefore, the cost weight is set at 0.333. The total counterproliferation value is highest for the Conventional ICBM followed by the hypervelocity kinetic energy weapon, the advanced airborne laser, and global eyes. The selection of the cost weight has a significant impact on the overall counterproliferation value of a system.

A number of graphs can be used to aid in the analysis of the results given by the counterproliferation decision model. Figure 4.12 plots the cost of a counterproliferation system versus the military counterproliferation value of a system. On the cost scale, a value of one indicates a relatively low cost, and a value of zero indicates a very high cost. Weapons with high capability and low cost are preferred.

A graph can be plotted showing the technological challenge of a counterproliferation system versus its military counterproliferation value. This graph is shown in Figure 4.13. The technological challenge of a system ranges from 0 to 20 (0 indicates that much development effort is required to create the system and 20 means technology exists today to develop the system). In the case of this plot, a low technological challenge coupled with a high military counterproliferation value indicates the preferred systems.

Figure 4.14 plots a system's technological challenge versus its total counterproliferation value. Again, the preferred systems are those which have a low technological challenge and a high total counterproliferation value.

Finally, a plot of cost utility versus technological challenge indicates outlying systems. Figure 4.15 plots this graph for the Vulcan's Forge systems evaluated. This plot is used to generally see if the values used for each system's utility cost and technological challenge make sense. The points should generally lie on the line plotted in the graph. Those points which lie far from the line should be investigated more closely to determine if the values make sense. For example, from this graph, the OD Tac Satellite and Global Eyes seem to lie far from the line. By investigating these systems further, both must be launched into space which increases their utility cost by more than what would be expected.

These four graphs show how counterproliferation systems may be evaluated using the counterproliferation model. The graphs can be used to eliminate systems from acquisition consideration. Systems are eliminated when they are dominated by other alternative systems. Figure 4.12 is used to show which systems are dominated in this analysis. A system is considered dominated when a system's military counterproliferation value is lower than that of another system and both systems have the same cost utility, and/or a system's cost is lower than another system and both systems have the same

military counterproliferation value. Using these requirements, the On-Demand Tactical Satellite dominates Gravimetric Reconnaissance because both have the same cost utility but the On Demand Tactical Satellite has a higher military counterproliferation value. For the same reason, the Advance Airborne Laser dominates the RF weapon and SCUD mine. So both alternatives, Gravimetric reconnaissance and RF Weapon and SCUD Mine, can be eliminated from any future analysis. The model, therefore, develops a meaningful way for dissimilar systems to be compared.

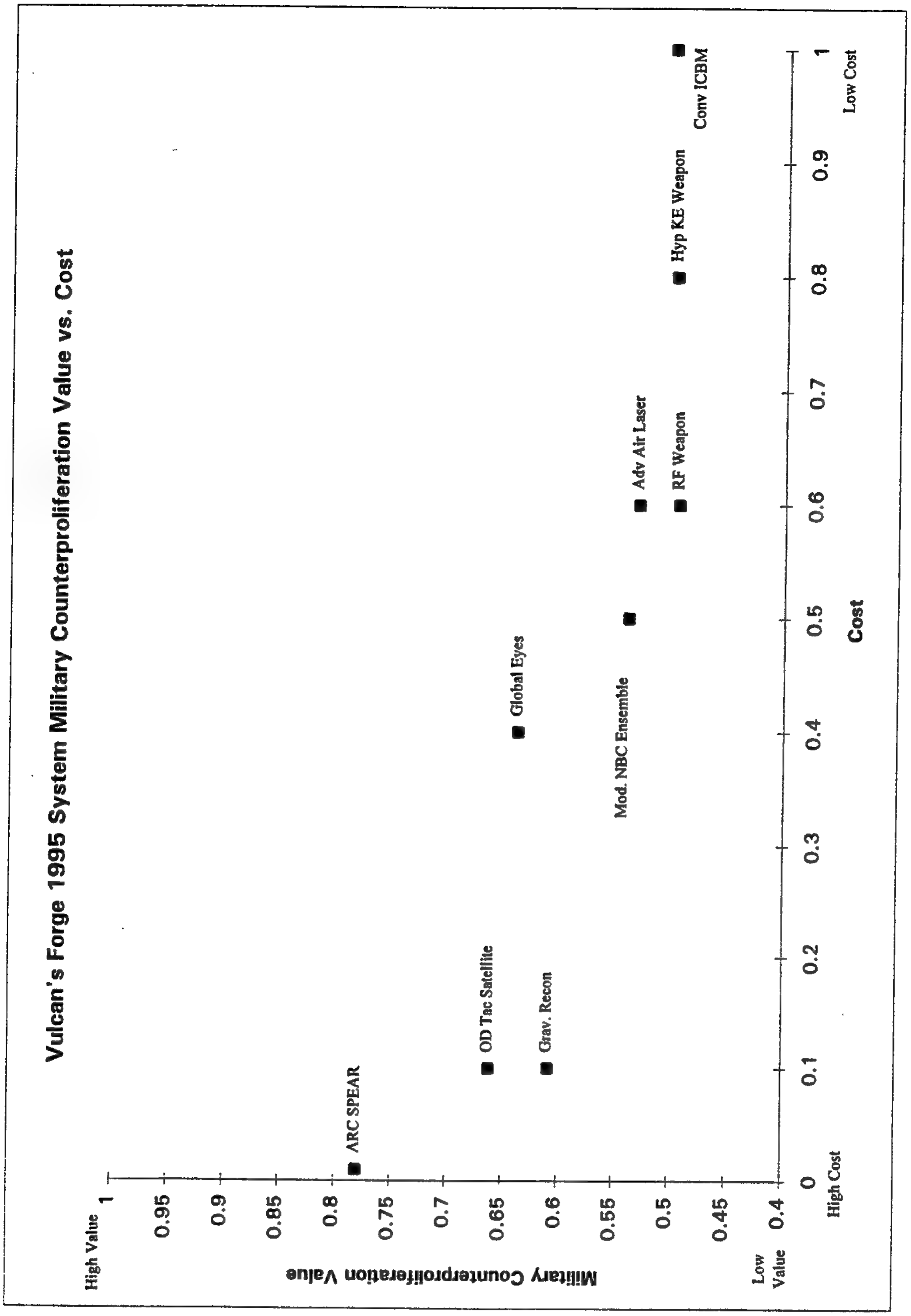

Figure 4.12 Vulcan's Forge 1995 System Military Counterproliferation Value versus Cost

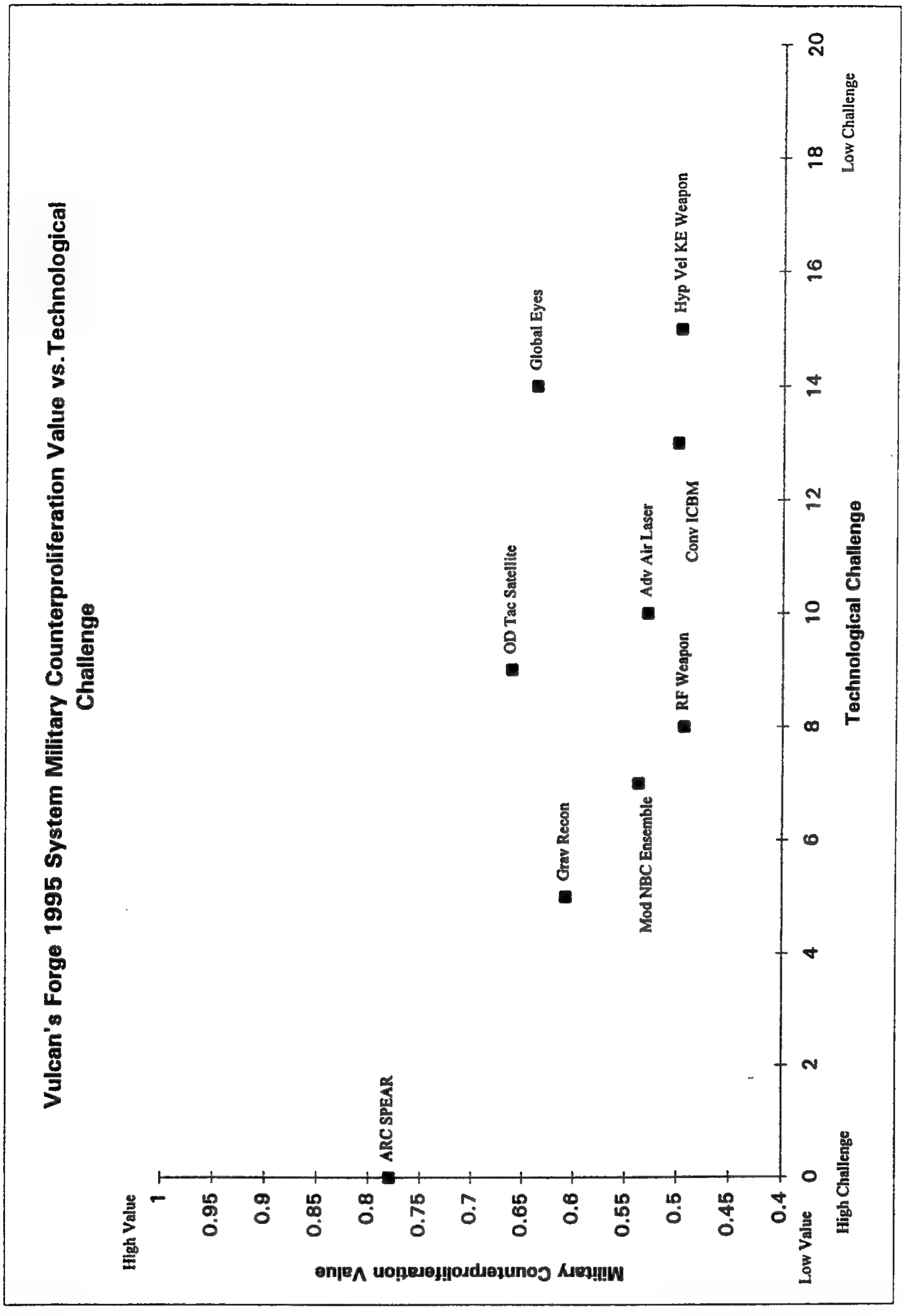

Figure 4.13 Vulcan's Forge 1995 System Military Counterproliferation Value versus Technological Challenge

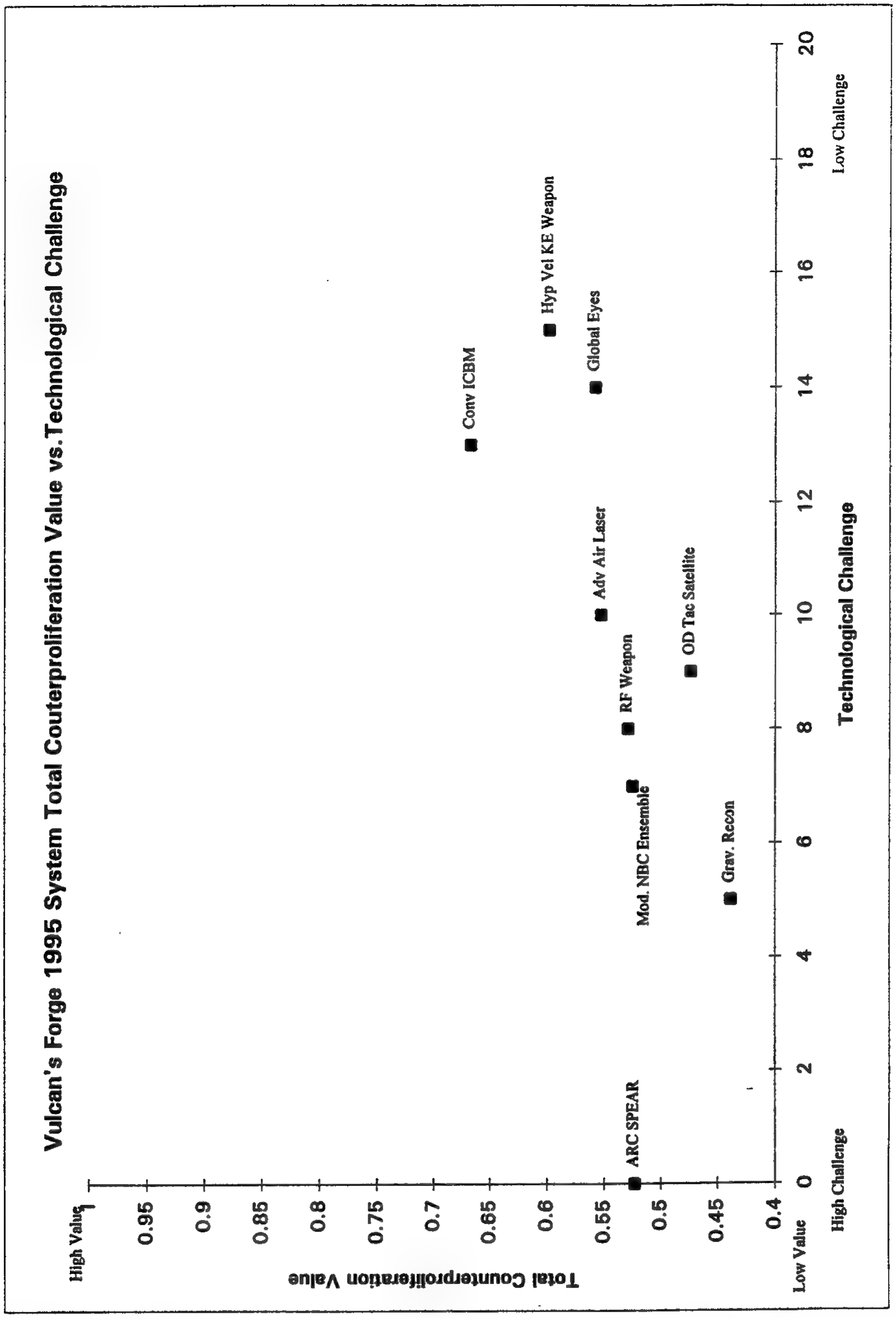

Figure 4.14 Vulcan's Forge 1995 System Total Counterproliferation Value versus Technological Challenge

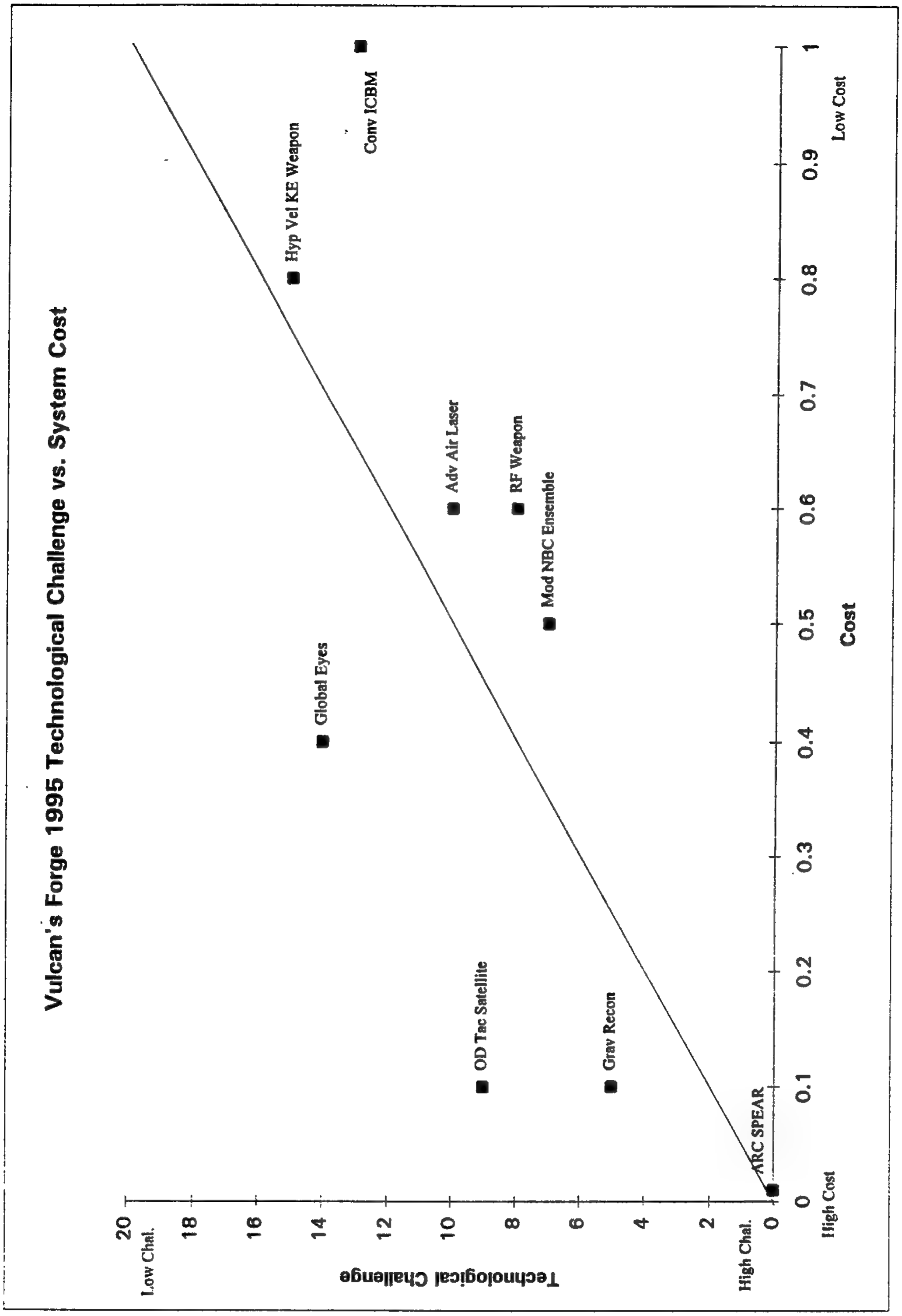

Figure 4.15 Vulcan's Forge 1995 System Technological Challenge versus Cost

V. Conclusions and Recommendations

This chapter identifies lessons learned from the counterproliferation model. Areas of further study which might improve the model are also discussed.

Conclusions

The primary objective of this research was to develop a method to evaluate Air Force counterproliferation systems to determine their contribution to the goals of U.S. counterproliferation policy. The influence diagram used to describe the counterproliferation process breaks the process into its fundamental parts. The influence diagram allows this process to be easily explained to decision makers. The results provide a traceable means to evaluate different counterproliferation systems.

The evaluation of perfect counterproliferation systems in Chapter IV indicates that counterproliferation efforts should focus on the development of intelligence and defensive systems which support counterproliferation. The sensitivity analysis of perfect offensive, perfect defensive, and perfect intelligence systems supports these findings. When parameters were varied in the model, the results remained unchanged. A perfect intelligence system is preferred to a perfect defensive system which is preferred to a perfect offensive system. The acquisition of an intelligence system generally increases the U.S.'s ability to accomplish counterproliferation missions more than the acquisition of an offensive system does.

The programming system used (DPL) and the model designed to evaluate counterproliferation systems are simple to use and easy to operate. The inputs required by the model are clearly defined. As in any model, a number of assumptions are made, but the assumptions used in this model generally tend to ensure that the U.S. has a balanced group of counterproliferation systems. As events and policies change, the assumptions

contained within the model can be updated. The results obtained from evaluating two different systems in the counterproliferation model are comparable given that the same baseline data is used. This quality allows use of the counterproliferation model to compare the relative impact on the U.S.'s counterproliferation policy of two distinctly different systems, such as an intelligence system and an offensive system.

Table 5.1 Key Questions used to Evaluate Counterproliferation System

Questions:	Effects:
What type of system is being evaluated?	System is an Offensive system, a Defensive system, an Intelligence system or some combination of the three system types.
If the system has Offensive capabilities: 1. Is the system a first strike and/or a restrike system? 2. What is the probability that the system can destroy an NBC, Chem/Bio or a nuclear site or how much more effective is the system at destroying the sites than current U.S. counterproliferation systems?	**If a first strike system only:** *Offensive System Effects* node is effected **If a restrike system only:** *Offensive Sys Effects on Restrike* node effected **If either is appropriate:** Both offensive nodes effected. Probabilities of Kill for NBC, Chem/Bio, and Nuclear Sites
If the system has Defensive capabilities: 1. What are the probabilities that the system can neutralize a Nuclear, a Chemical or a Biological attack with minimal casualties or how much more effective is the system at neutralizing attacks than current U.S. counterproliferation systems?	The *Defense Effectiveness* node is effected. Probabilities of Neutralizing Nuclear, Chemical and Biological Attacks.

If the system has Intelligence capabilities:	
1. Does the system detect WMD facilities, detect WMD attacks and/or provide battle damage assessment?	**If system detects WMD facilities:** The *Detect WMD Facility or Site* node is effected. **If system detect a WMD attack:** The *Detect Use of WMD* node is effected. **If system provides BDA:** The *BDA Report* node is effected.
2. **If the system detects WMD facilities:** What is the probability that the system can detect NBC, Chem/Bio or nuclear site or how much more effective is the system at detecting the sites than current U.S. counterproliferation systems?	Probabilities of detecting NBC, Chem/Bio and Nuclear facilities.
3. **If the system detects a WMD attack:** What is the probability that the system can detect nuclear, chemical or biological attack or how much more effective is the system at detecting WMD attacks than current U.S. counterproliferation systems?	Probabilities of detecting nuclear, chemical, and biological use.
4. **If the system provides BDA:** What is the probability that the system reports a destroyed site as destroyed and not destroyed site as destroyed or how much more effective is the system at assessing damage than current U.S. counterproliferation systems?	Probabilities of reporting a site destroyed given it is destroyed and reporting a site destroyed given it is not destroyed.
What is the utility cost of the new system or the level of technology required to produce the new system?	Determines the relative cost of the new system or the level of effort required to acquire the new system.

From the evaluation of the Vulcan's Forge systems, some fundamental questions are identified which must be answered in order to evaluate a counterproliferation system. Table 5.1 shows these questions. These questions force system advocates to characterize how a proposed counterproliferation system accomplishes the U.S.'s goals for

counterproliferation. Of all the insights gained by this research, these questions are the most important in determining the worth of a counterproliferation system.

Further Research

This research defines a method to evaluate military counterproliferation systems. However, to more clearly understand the contribution of each counterproliferation system to the U.S.'s accomplishment of its counterproliferation policy, more study is needed in the following areas:

- The model currently only identifies WMD sites as one type of facility. A potential modification of the model should include an update of the influence diagram to include fixed, fixed hardened, and mobile WMD sites. These options should be incorporated in the model to provide an additional level of credibility to the results of the model.

- The model currently defines an attack in terms of a specific WMD type of attack (e.g. a nuclear attack). A potential modification to the model should define the type of delivery vehicles used to deliver the WMD. This capability would allow the model to more fully explore defensive alternatives such as boost phase intercept versus terminal phase intercept by a theater ballistic missile defense system.

- As the model is currently constructed, striking and destroying a target twice, striking a non-WMD target and attempting to neutralize a false WMD attack do not affect the counterproliferation value produced by the model. Study should be made on changing the value function used in the counterproliferation model

which includes a penalty for attacking a destroyed target, attacking a non-WMD site or attempting to neutralize a false WMD attack.

- The incorporation of the two previous modifications to the model require additional modification to the intelligence nodes in order to take into account new intelligence requirements caused by their inclusion.

- The probability input in the *Willingness to Act* node represents the probability that the public and government accept the use of an offensive weapon against a WMD target. A study should be conducted to determine the best measure of effectiveness for this value. In addition, it is assumed that only offensive weapons are affected by *Willingness to Act*, but certain defensive weapons might also be affected by this factor. More study is needed on this factor.

APPENDIX A

Vulcan's Forge System Concepts

Vulcan's Forge 1995 is a long range technology planning wargame sponsored by Air Force Materiel Command and the U.S. Air Force Director of Plans. The wargame's purpose is to evaluate different technologies for their use in counterproliferation of WMD. The purpose of this appendix is to analyze the system concepts to be used in the wargame to determine how they would fit into the counterproliferation influence diagram. In addition, nine systems are selected for evaluation by the counterproliferation influence diagram.

The Vulcan's Forge System Concepts document contains 50 different systems which can be used to counter the proliferation of WMD. Table A.1 lists all the system concepts to be used in Vulcan's Forge and classifies all of them by their ability to accomplish an offensive, a defensive, and/or an intelligence mission. The counterproliferation influence diagram assumes counterproliferation systems can be classified as offensive, defensive or intelligence. The Vulcan's Forge systems indicate that the assumption that a counterproliferation system falls into at least one of the above missions is correct.

An examination of Table A.1 shows that 21 of the systems are designed for an offensive counterproliferation mission, 14 have a defensive counterproliferation mission and 21 are involved in some type of intelligence counterproliferation mission. Of the 21 having an intelligence counterproliferation mission, only 18 are purely intelligence gathering systems. The grouping of the Vulcan's Forge system concepts indicates that Air Force experts seem to concentrate on developing offensive weapons first, intelligence gathering systems next, and defensive systems last. The model results shown in Chapter

IV indicate that deficiencies in intelligence and defensive systems should be addressed before acquisition of new offensive weapon systems.

The Vulcan's Forge system concepts provide a diverse set of unclassified counterproliferation systems to evaluate. For this reason, nine Vulcan's Forge system concepts are selected to be evaluated in the counterproliferation model developed in this research. Three systems are selected from each system category - offensive, defensive and intelligence as shown in Table A.2. The probabilities used to reflect the system capability are gross estimates and not official. It is useful, however, to illustrate how these types of systems are input into the model and demonstrate the analysis which can be accomplished.

Table A.1 Vulcan's Forge System Concepts

System	Offensive	Defensive	Intelligence		
			Strategic	Tactical	BDA
Air-deliverable, Unattended, Mini-ground Sensors			X		
ARC SPEAR (Autonomous or Remotely Controlled Solar Powered, Extended Altitude and Range)		X	X	X	
Directed Energy Weapons	X	X			
Electromagnetic Markers			X		
Enhanced Airborne Radar Surveillance				X	
Global Eyes			X		X
Hypervelocity Kinetic Energy Winged Weapon	X				
High-Altitude Long Endurance Airborne Platform			X		X
Hypersonic Reconnaissance/Interceptor/Strike Vehicle	X				
Hypersonic Long Range Missile	X				
Massive Airlift System	X			X	
Modular "Genetically Engineered" NBC Ensemble		X			
Miniature Military Robot			X		
Mini-Unmanned Air Vehicle (MUAV)			X		X
Non-Destructive ASAT Technology	X				
Nanotechnology for Destroying WMD	X				
Non-Lethal to Lethal Turnable Weapons	X				

On-Demand Tactical Satellite			X	X	X
PATCH (Pharmaceuticals Autonomously Timed Control Harness)		X			
Remote Computer Shutdown Chip	X				
Radio Frequency Weapon and SCUD mine	X				
Smart Air Scatterable Mines	X				
Special Operations Forces (SOF) Insertion Aircraft	X				
Sticky Foam	X				
Sterilizing Radiation	X				
Transatmospheric Vehicle (TAV)	X		X		
Thermal Accelerants	X				
Very Hard Target Weapon	X				
WMD Marking and Tracking System			X		
Advanced Airborne Laser		X			
Anti-Missile Mine		X			
Gravimetric Reconnaissance of Underground Facilities			X		
Integrated Satellite/Launcher Concept (ISLC)		X			
Mobile Remote Laser Sensing (MRLS)			X	X	
Theater Applications of Laser Radar (TALR)			X	X	X
On Orbit High Power Microwave Kill Vehicle		X			
Terrestrial High Power Microwave Weapon	X				
Brilliant Pebbles		X			
Global Precision Response Capability	X				
Global Surveillance, Reconnaissance, and Targeting System				X	X
Space Based High Energy Laser System		X			X
Global Prompt Precision Strike using Conventional ICBM	X				
High Powered Microwave System	X	X			
Solar Mirror System		X			
Particle Beam Weapon System	X	X			
Photolytic Neutralization of Chemical Agents		X			
Scatterable Lab on a Chip Chemical and Biological Agent Sensors				X	
Over the Horizon Radar				X	
Intelligence Data Storage and Retrieval System			X		
Expert System Information Analysis			X		

A brief definition of each of the systems to be evaluated allows a more fundamental understanding of the results. The three offensive systems are the

Hypervelocity Kinetic Energy Winged Weapon, Radio Frequency Weapon and SCUD Mine, and Global prompt precision strike using conventional ICBM. Hypervelocity Kinetic Energy Winged Weapon is a hard target kill weapon with a range of 5000-7000

Table A.2 Vulcan's Forge System Concepts Notional Data Used in Evaluation

System	Will to Act	Off Prb Kill	Def Prb Neut	Intelligence			Tech Chal	Cost
				Strat	Tac	BDA		
Radio Frequency Weapon and Scud Mine	1	0.9					8	0.6
Hypervelocity Kinetic Energy Winged Weapon	1	0.93					15	0.8
Global Prompt Precision Strike Using Conventional ICBM	1	0.96					13	1
Modular "Genetically Engineered" NBC Ensemble	1		Nuc: Chm:0.8 Bio:0.8				7	0.5
Advanced Airborne Laser	1		Nuc: 0.6 Chm:0.5 Bio: 0.5				10	0.6
ARC SPEAR (Autonomous or Remotely Controlled Solar Powered, Extended Altitude and Range	1		Nuc: 0.7 Chm:0.6 Bio: 0.6	NBC: 0.8 Chm/Bio:0.5 Nuc: 0.7	Nuc: 0.8 Chm: 0.5 Bio: 0.5		0	0.01
Global Eyes	1			NBC: 0.7 Chm/Bio:0.5 Nuc: 0.6		Given Kill: NK:0.1	15	0.4
Gravimetric Reconnaissance of Underground Facilities	1			NBC: 0.7 Chm/Bio:0.5 Nuc: 0.5			14	0.1
On-Demand Tactical Satellite	1			NBC: 0.75 Chm/Bio: 0.4 Nuc: 0.7	Nuc: 0.75 Chm:0.4 Bio: 0.4	Given Kill: NK:.05	9	0.1

miles and a terminal speed of mach 4+ (1:16). Radio Frequency Weapon and SCUD mine is a tunable RF source which outputs large pulses which disrupt electronics and can penetrate reinforced bunkers (1:45). A global prompt precision strike using a conventional ICBM provides a prompt, low cost, hard target kill capability (1:87).

The three defensive systems selected for evaluation are the Modular "Genetically Engineered" NBC Ensemble, the Advanced Airborne Laser, and ARC SPEAR. Modular "Genetically Engineered" NBC Ensemble is a personal protection system which allows the capability to operate in a "contaminated" environment and provides protection of personnel during transportation of WMD (1:27). The advanced airborne laser represents an active defensive capability against WMD attack in which a high energy laser defeats theater ballistic missile attacks in the boost phase (1:63). ARC SPEAR is a high altitude blimp system which can monitor an opponent's territory for WMD production and use a sterilizing beam of solar energy to neutralize a chemical or biological threat with pinpoint precision (1:6).

The final three systems evaluated are intelligence gathering systems. They are Global Eyes, On-Demand Tactical Satellite, and Gravimetric reconnaissance of underground facilities. Global Eyes is a very large aperture (300 meters) visible and infrared (IR) wavelength reconnaissance system based in a geostationary orbit and capable of direct earth observation. It has near real time coverage of most of the earth's surface, and a visible and IR resolution of 1 to 2 feet (1:14). On-Demand Tactical Satellite allows real time ability to monitor WMD production storage and movement in addition to BDA and tactical missile launch warning and tracking (1:39). Gravimetric reconnaissance of underground facilities provides the ability to detect structures and facilities located several hundred feet below ground from low altitude and/or ground survey (1:67).

APPENDIX B

Model Validation

An important aspect of any model is its ability to provide correct results. To validate the model, a number of tests were accomplished to determine if the model produces the correct results. The military system value portion of the model can be separated into two parts: an offensive and a defensive part. A decision tree is used to describe the value model for each of these parts. Extreme values were input into the model to determine if the results were consistent with actions.

Value Model Decision Trees. The value model described in the *Military Counterproliferation Value* node can be broken down into an offensive value model and a defensive value model. Each value model is described in a decision tree format to clearly indicate the value dependence, and the column specifying value at the end of each tree indicates the value model result for each branch. The value model in the *Military Counterproliferation Value* node takes the maximum of the offensive and defensive portions of the model to produce a military counterproliferation value for a system.

The offensive value model is describe in Figure B.1. This figure shows the uncertainties and values which impact the offensive portion of the *Military Counterproliferation Value.* The results of the decision tree indicate that the model only produces a value offensively if an offensive counterproliferation system is used. An offensive counterproliferation system is used only if a WMD facility or site is detected and the U.S. is willing to act against that site. The decision to use a weapon occurs in the *Use Offensive CP System* decision node. The decision tree further indicates that if an offensive system destroys a WMD site in the first strike, the value of the offensive portion of the value model is always one. If a WMD is not destroyed in the first strike, a value of one can only be gained offensively if the BDA report indicated that the site is not

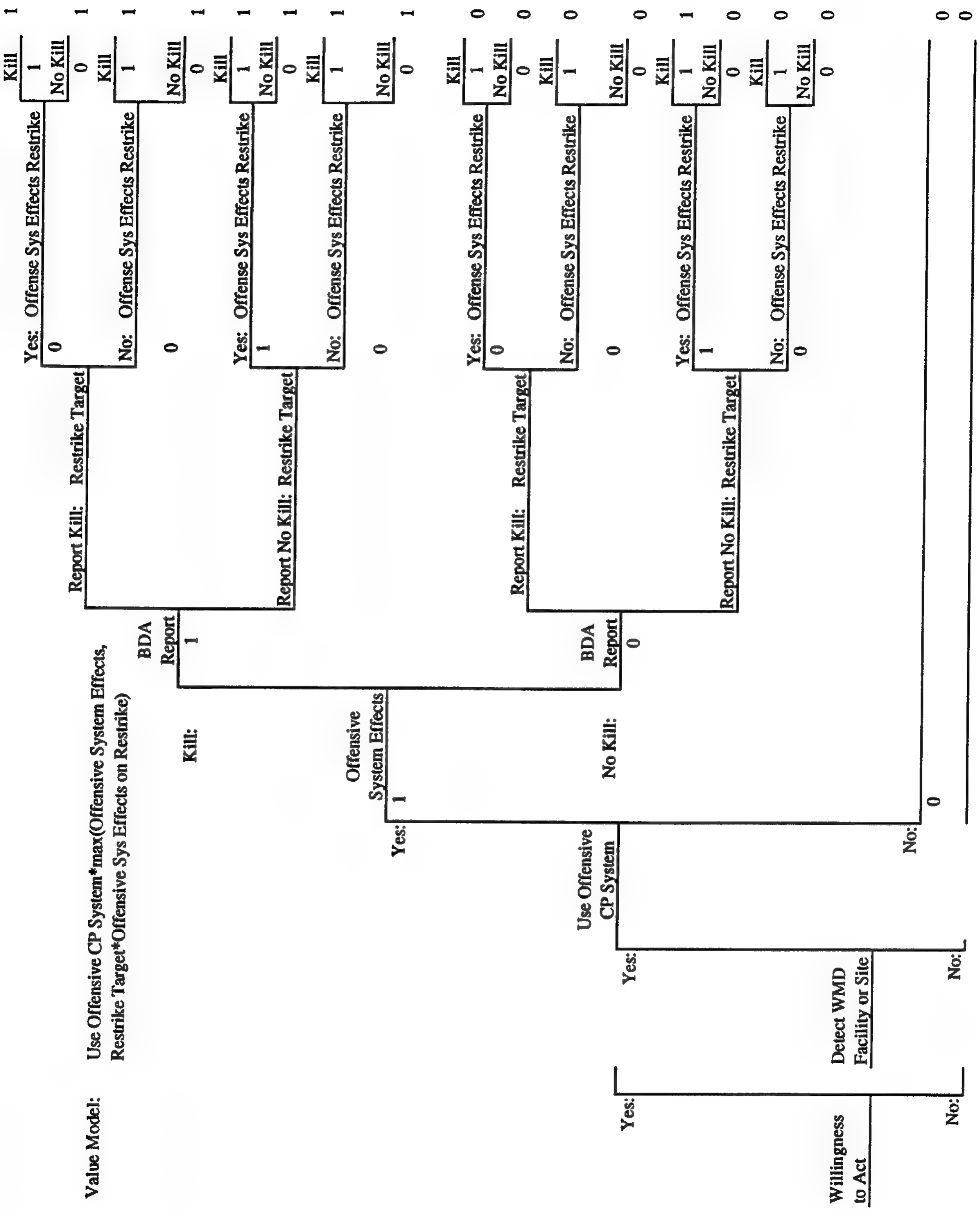

Figure B.1 Value Tree of Offensive Portion of the Counterproliferation Model

destroyed, the site is marked to be restruck, and the offensive system destroys the WMD site during restrike. Otherwise, the offensive portion of the model indicates a value of zero. Intuitively this makes sense, since the offensive portion of the military counterproliferation value should be other than zero only if an offensive system is used and it destroys the WMD site or an offensive system is used and destroys a WMD site, the second time it attacks the site.

The defensive portion of the *Military Counterproliferation Value* node is shown in Figure B.2. This tree indicates that for the defensive portion of the military counterproliferation model to have a positive value, the United States must detect an adversary's WMD attack and then employ a defensive counterproliferation system. A value of one is only assessed if the defensive counterproliferation system neutralized the WMD threat; otherwise, a value of zero is assessed. In addition, if the U.S. does not detect an attack or use a defensive system, a counterproliferation value of zero is assessed for the defensive portion of the military counterproliferation value. Again, the decision tree indicates that the result of the value model meets expectations.

Military Counterproliferation Value Function Extremes. An examination of the results of the *Military Counterproliferation Value* function evaluated at some extreme cases also helps determine if the function is working properly. Table B.1 lists the cases run and their results. The alternative evaluated indicates the type of data run through the model. For example, "Only Perfect Intelligence" indicates a run of the model was made with a system which had perfect probabilities and values for all intelligence nodes and no capability or value in offense and defensive nodes. "Perfect Offense and Defense Only" indicates a run where offensive and defensive nodes were perfect and no intelligence capability was available.

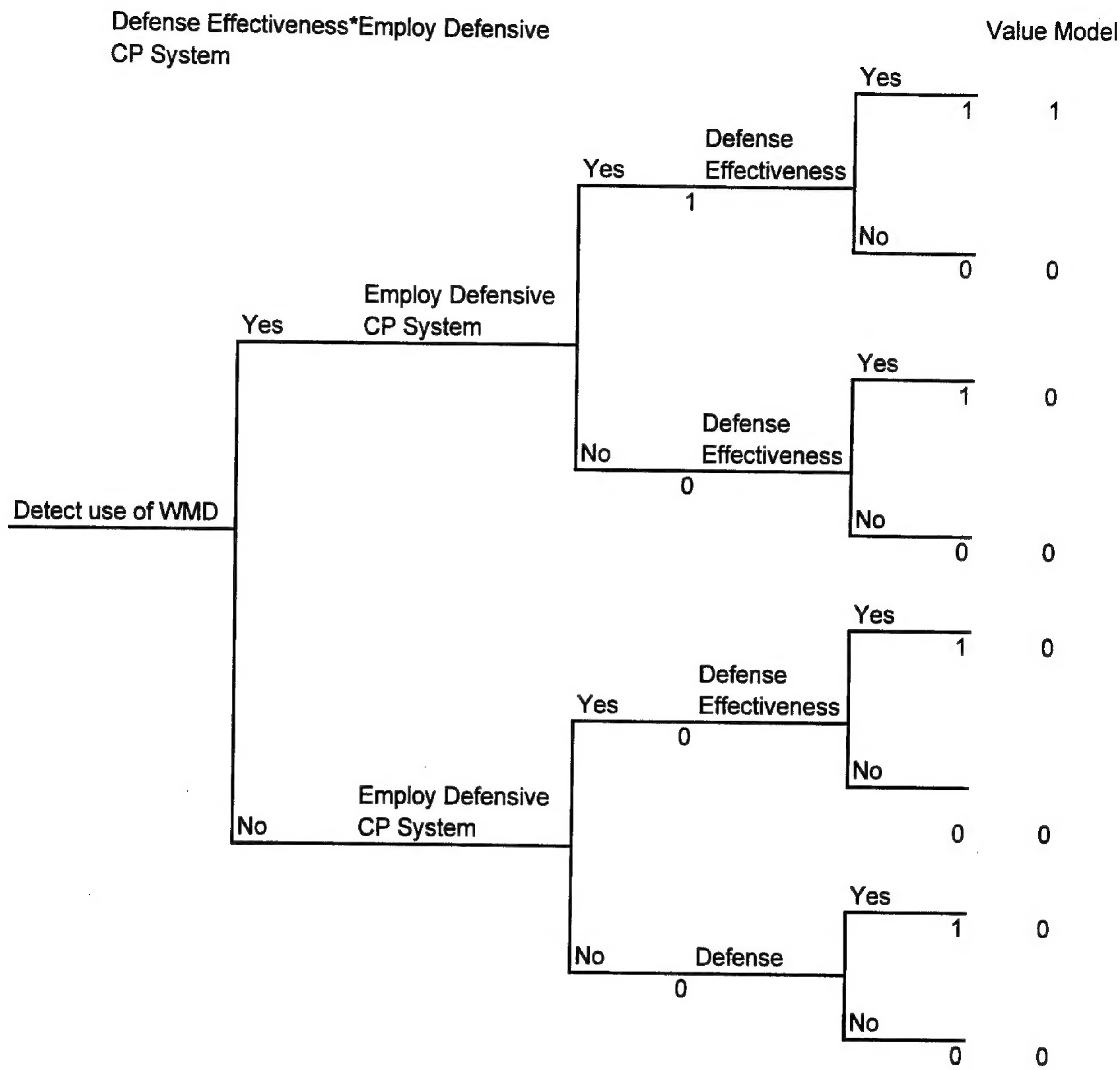

Figure B.2 Value Tree of Defensive Portion of the Counterproliferation Model

Table B.1 Extreme Alternatives Run and Results

Alternative Evaluated	Military Counterproliferation Value Result
Only Perfect Intelligence	0
Only Perfect Offense	0
Only Perfect Defense	0
Perfect Offense and Defense Only	0
Perfect Offense and Intelligence Only	1
Perfect Defense and Intelligence Only	1
Perfect Offense, Defense and Intelligence	1
WMD Type: Nothing (Prob. 1)	0

An analysis of the results indicates that if only one type of system is selected to be perfect and all others are set to zero, the military counterproliferation value is zero. If perfect offense and defense are selected without intelligence, a value of zero is realized. These values make sense, since a perfect intelligence system provides no value by itself and offensive and defensive systems require an intelligence system to be effectively employed.

Finally, the model was run with the probability of an adversary possessing no WMD set at one. The military counterproliferation value of this case was zero. A result of zero is expected since the logic of the model indicates that if an opponent has no WMD, counterproliferation systems would be of no value against that adversary.

Summary

The results of this investigation indicate that the model developed in this research is providing reasonable results. The decision trees indicate the logic used in the *Military Counterproliferation Value* node's value function. The value results of the decision trees are consistent with expectation. In addition, the extreme cases used to test the model provide results consistent with expectations of the model and indicate that the model is functioning correctly.

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Vita

Captain Stanley Stafira Jr. was born on 22 April 1966 in Alexandria, Virginia. He graduated from Garfield Senior High School in Woodbridge, Virginia in 1984 and attended the University of Virginia, graduating with a Bachelor of Science in Aerospace Engineering in 1988. Upon graduation, he received a regular commission in the USAF and a distinguished graduate award. While waiting 10 months to begin active duty in the Air Force, he was employed at Analytical Services, Inc. (ANSER), an Air Force Think Tank, where he worked in the Missile Planning Division. He began active service in the USAF at Vandenberg AFB, California where he attended Undergraduate Missile Training (UMT) receiving a distinguished graduate award. Upon graduation, he was assigned to Francis E. Warren AFB, Wyoming. He began as a deputy missile combat crew commander in the 400th Strategic Missile Squadron where he controlled a flight of 10 Peacekeeper Missiles. He was then selected to become a deputy missile combat crew (MCC) instructor for the 90th Strategic Missile Wing (SMW). He was later assigned to be the Senior Deputy Peacekeeper Missile Combat Crew Commander for the 90th SMW. He was responsible for coordinating and supervising over 30 wing instructors. He returned to the 400th missile squadron to upgrade to Missile Combat Crew Commander. He was soon selected to become a Standardization and Evaluation MCC Commander. In this position, it was his responsibility to evaluate all Peacekeeper MCC members' abilities to perform their functions. He was assigned as Senior Standardization and Evaluation MCC Commander where he was responsible for the training and supervision of 16 MCC evaluators until entering the Graduate School of Engineering, Air Force Institute of Technology, in September 1993.

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